



PALESTINE POLYTECHNIC UNIVERSITY

FACULTY OF MEDICINE

Lecture Notes

Biophysics: Physics for Life

Sciences

Dr. Ayman Sweiti & Dr. Othman Zalloum

✉ sweitia@ppu.edu & ozalloum@ppu.edu

Fall 2024

Fluids (Chapter 11)

- 1 States of Matter and Mass Density
- 2 Pressure in a fluid
- 3 Pressure and depth in a static fluid
- 4 Pressure Gauges
- 5 Pascal's principle
- 6 Archimedes' Principle
- 7 Fluids in motion (Fluid dynamics)
- 8 Bernoulli's equation and applications

1 / 57

States of Matter and Mass Density

States of Matter

Solid: Has a definite volume and shape

Liquid: Has a definite volume but not a definite shape

Gas: unconfined: Has neither a definite volume nor shape

Fluids: Fluids are materials that can flow, and they include both gases and liquids.

Statics and Dynamics with Fluids:

Fluid Statics: Describes fluids at rest

Fluid Dynamics: Describes fluids in motion

2 / 57

Mass Density

The mass density of a liquid or gas is one of the important factors that determine its behavior as a fluid.

Density is defined as the mass per unit volume of the substance

$$\rho = \frac{m}{V}$$

- The values of density for a substance vary slightly with temperature since volume is temperature dependent
- The various densities indicate the average molecular spacing in a gas is much greater than that in a solid or liquid
- A convenient way to compare densities is to use the concept of specific gravity.
- The specific gravity of a substance is its density divided by the density of a standard reference material, usually chosen to be water at 4 °C.

$$\text{specific gravity} = \frac{\text{density of substance}}{1000 \text{ kg}/\text{m}^3}$$

3 / 57

Density

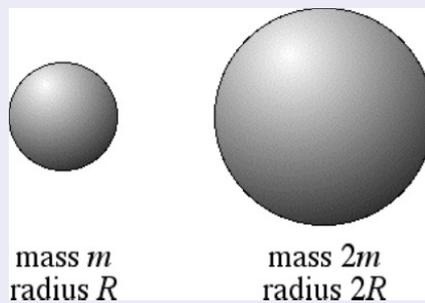
Table 11.1 Mass Densities^a
of Common Substances

Substance	Mass Density ρ (kg/m ³)		
<i>Solids</i>		<i>Liquids</i>	
Aluminum	2700	Blood (whole, 37 °C)	1060
Brass	8470	Ethyl alcohol	806
Concrete	2200	Mercury	13 600
Copper	8890	Oil (hydraulic)	800
Diamond	3520	Water (4 °C)	1.000×10^3
Gold	19 300	<i>Gases</i>	
Ice	917	Air	1.29
Iron (steel)	7860	Carbon dioxide	1.98
Lead	11 300	Helium	0.179
Quartz	2660	Hydrogen	0.0899
Silver	10 500	Nitrogen	1.25
Wood (yellow pine)	550	Oxygen	1.43

4 / 57

Question 1

The sphere on the right has twice the mass and twice the radius of the sphere on the left. Compared to the smaller sphere on the left, the larger sphere on the right has



- (A) twice the density
- (B) the same density
- (C) 1/2 the density
- (D) 1/4 the density
- (E) 1/8 the density

5 / 57

Pressure in a fluid

When a body is submerged in a fluid such as water, the fluid exerts a force perpendicular to the surface of the body at each point on the surface.

This force per unit area is called the pressure P of the fluid:

$$P = \frac{F}{A}$$

SI unit is Pascal (Pa), $1 \text{ Pa} = \text{N}/\text{m}^2$

Atmospheric pressure:

the pressure exerted by the weight of the atmosphere, which at sea level has a mean value of 101,325 pascals (roughly 14.6959 pounds per square inch).

$$1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$$

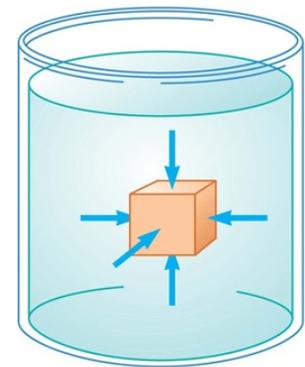


Figure: first image

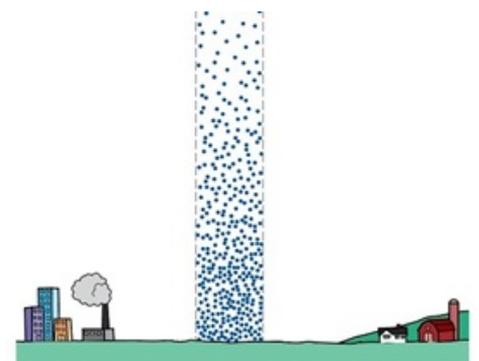


Figure: second image

6 / 57

Pressure and depth in a static fluid

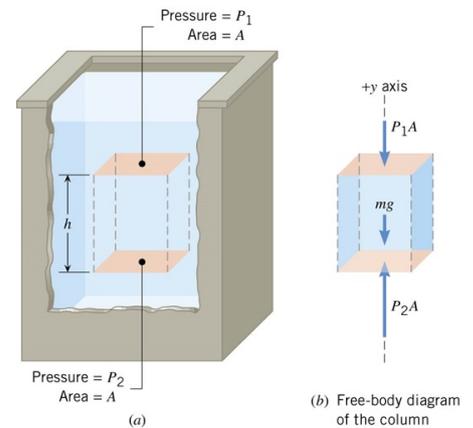
This figure shows a container of fluid in which one column of the fluid is outlined. The water sample contained by an imaginary rectangular shape

$$\sum \vec{F} = 0$$

$$P_2A - P_1A - mg = 0$$

$$P_2A - P_1A - \rho Ahg = 0$$

$$P_2 = P_1 + \rho gh$$

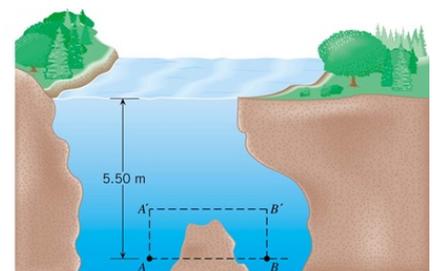


7 / 57

Pressure and depth in a static fluid

If level 1 is at the surface then. The pressure at level A has two contributions due to the atmosphere and due to the water above level A

- Pressure is a scalar quantity: Because it is proportional to the magnitude of the force.
- Unit of pressure is pascal (Pa),
- Pressure is a scalar and force is a vector
- The direction of the force producing a pressure is perpendicular to the area of interest

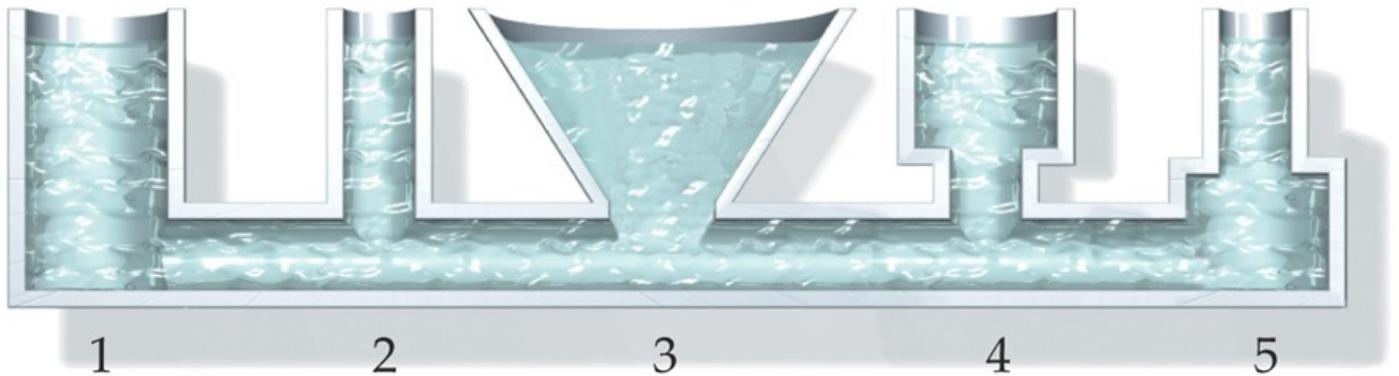


8 / 57

Pressure and depth in a static fluid

The pressure is affected by vertical distance h , but not by any horizontal distance within the fluid.

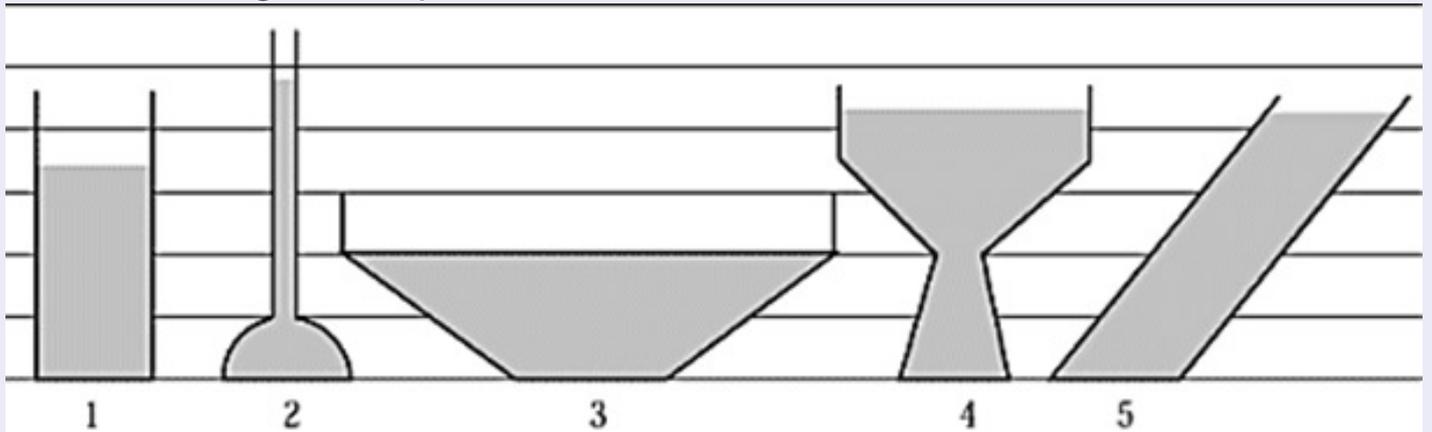
The pressure depends only on the depth of the water, not on the shape of the container, so at the same depth the pressure is the same in all parts of the container



9 / 57

Question 2

The vessels in the figure contain liquids of the same density. The vessel that has the greatest pressure at its base is



- A 1
- B 2
- C 3
- D 4
- E 5

10 / 57

Check Your Understanding 1

As you climb a mountain, your ears “pop” because of the changes in atmospheric pressure. In which direction, outward or inward, does your eardrum move (a) as you climb up and (b) as you climb down?

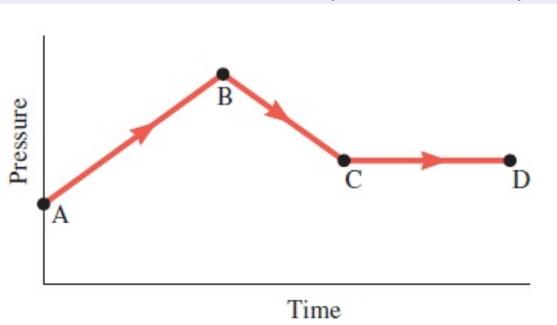
Check Your Understanding 2

A bottle of juice is sealed under partial vacuum, with a lid on which a red dot or button is painted. Around the button the following phrase is printed: Button pops up when seal is broken. Why does the button remain pushed in when the seal is intact? (a) The pressure inside the bottle is greater than the pressure outside the bottle. (b) The pressure inside the bottle is less than the pressure outside the bottle. (c) There is a greater force acting on the interior surface of the seal than acts on the exterior surface.

11 / 57

Check Your Understanding 4

A scuba diver is swimming under water, and the graph shows a plot of the water pressure acting on the diver as a function of time. In each of the three regions, (a) $A \rightarrow B$, (b) $B \rightarrow C$, and (c) $C \rightarrow D$, does the depth of the diver increase, decrease, or remain constant?



12 / 57

Common Units of Pressure

Unit	Average Air Pressure at Sea Level
pascal (Pa)	101,325
kilopascal (kPa)	101.325
atmosphere (atm)	1 (exactly)
millimeters of mercury (mmHg)	760 (exactly)
torr (torr)	760 (exactly)
pounds per square inch (psi, lbs./in ²)	14.7

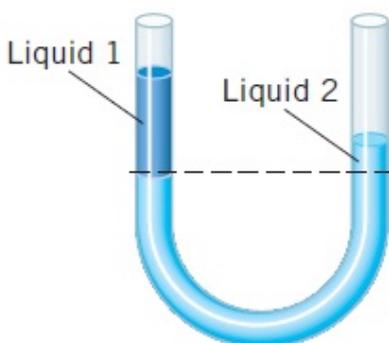
8

13 / 57

Focus on Concepts 4

Two liquids, 1 and 2, are in equilibrium in a U-tube that is open at both ends, as in the drawing. The liquids do not mix, and liquid 1 rests on top of liquid 2. How is the density ρ_1 of liquid 1 related to the density ρ_2 of liquid 2?

- A ρ_1 is equal to ρ_2 because the liquids are in equilibrium.
- B ρ_1 is greater than ρ_2 .
- C ρ_1 is less than ρ_2
- D There is not enough information to tell which liquid has the greater density.



14 / 57

Problem 11

An airtight box has a removable lid of area $1.3 \times 10^{-2} \text{ m}^2$ and negligible weight. The box is taken up a mountain where the air pressure outside the box is $0.85 \times 10^5 \text{ Pa}$. The inside of the box is completely evacuated. What is the magnitude of the force required to pull the lid off the box?

15 / 57

Pressure Gauges

The barometer consist of a long, mercury-filled tube closed at one end and inverted into a container of mercury

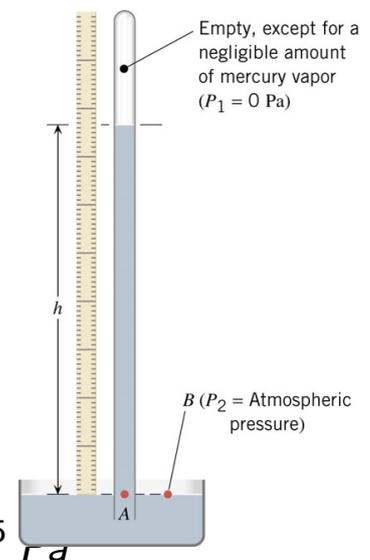
$$P_2 = P_1 + \rho gh$$

If $P_1 = 0$ because of vacuum
then

$$P_{atm} = \rho gh$$

At sea level $h=76 \text{ cm}$

$$P_{atm} = 13595 \text{ kg/m}^3 \times 9.8 \text{ m/s}^2 \times 0.76 \text{ m} = 1.013 \times 10^5 \text{ Pa}$$



16 / 57

Pressure Gauges: Pressure Measurements: Manometer

- A device for measuring the pressure of a gas contained in a vessel.
- One end of the U-shaped tube is open to the atmosphere
- The other end is connected to the pressure to be measured
- Pressure in container is:

$$P_2 = P_1 + \rho gh$$

- P_2 is the absolute pressure
- The gauge pressure is $P_2 - P_{atm} = \rho gh$
- This is This is what you measure in your tires, blood pressure.

The gauge pressure is the amount by which the container pressure differs from atmospheric pressure.

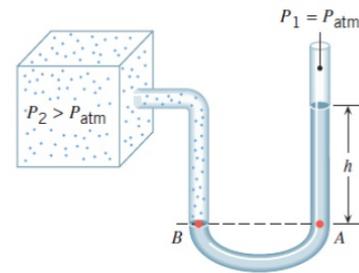
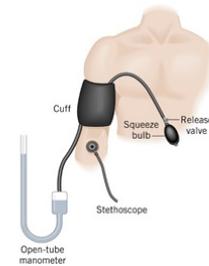


Figure 11.12 The U-shaped tube is called an open-tube manometer and can be used to measure the pressure P_2 in a container.



17 / 57

Absolute pressure

is zero-referenced against a perfect vacuum, so it is equal to gauge pressure plus atmospheric pressure.

Gauge pressure

is zero-referenced against ambient air pressure, so it is equal to absolute pressure minus atmospheric pressure.

18 / 57

Check Your Understanding 5

A 15 meter high tank is closed and completely filled with water. A valve is then opened at the bottom of the tank and water begins to flow out.

When the water stops flowing, will the tank be completely empty, or will there still be a noticeable amount of water in it?

Check Your Understanding 6

Could you use a straw to sip a drink on the moon? (a) Yes. It would be no different than drinking with a straw on earth. (b) No, because there is no air on the moon and, therefore, no air pressure to push the liquid up the straw. (c) Yes, and it is easier on the moon because the acceleration due to gravity on the moon is only of that on the earth.

19 / 57

Check Your Understanding 7

A scuba diver is below the surface of the water when a storm approaches, dropping the air pressure above the water. Would a sufficiently sensitive pressure gauge attached to his wrist register this drop in air pressure? Assume that the diver's wrist does not move as the storm approaches.

Question 3

A glass is filled with water. The gauge pressure at the top of the glass is zero and the gauge pressure at the bottom is P . A second glass with three times the height and twice the diameter is also filled with water. What is the pressure at the bottom of the second glass?

- (A) P
- (B) $2P$
- (C) $3P$
- (D) $3P/2$
- (E) $3P/4$

20 / 57

Question 4

If the gauge pressure is doubled, the absolute pressure is

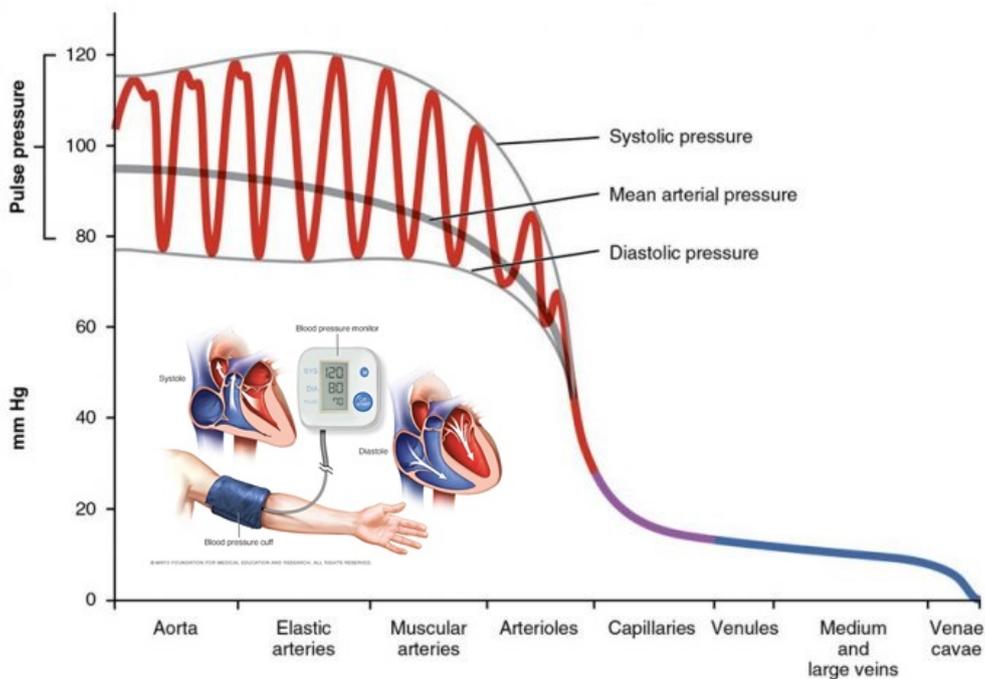
- (A) halved.
- (B) doubled.
- (C) unchanged.
- (D) squared.
- (E) Not enough information is given to determine the answer.

21 / 57

The physics of blood pressure.

Blood pressure

is the force exerted by blood upon the walls of the blood vessels or the chambers of the heart.



22 / 57



The physics of blood pressure.

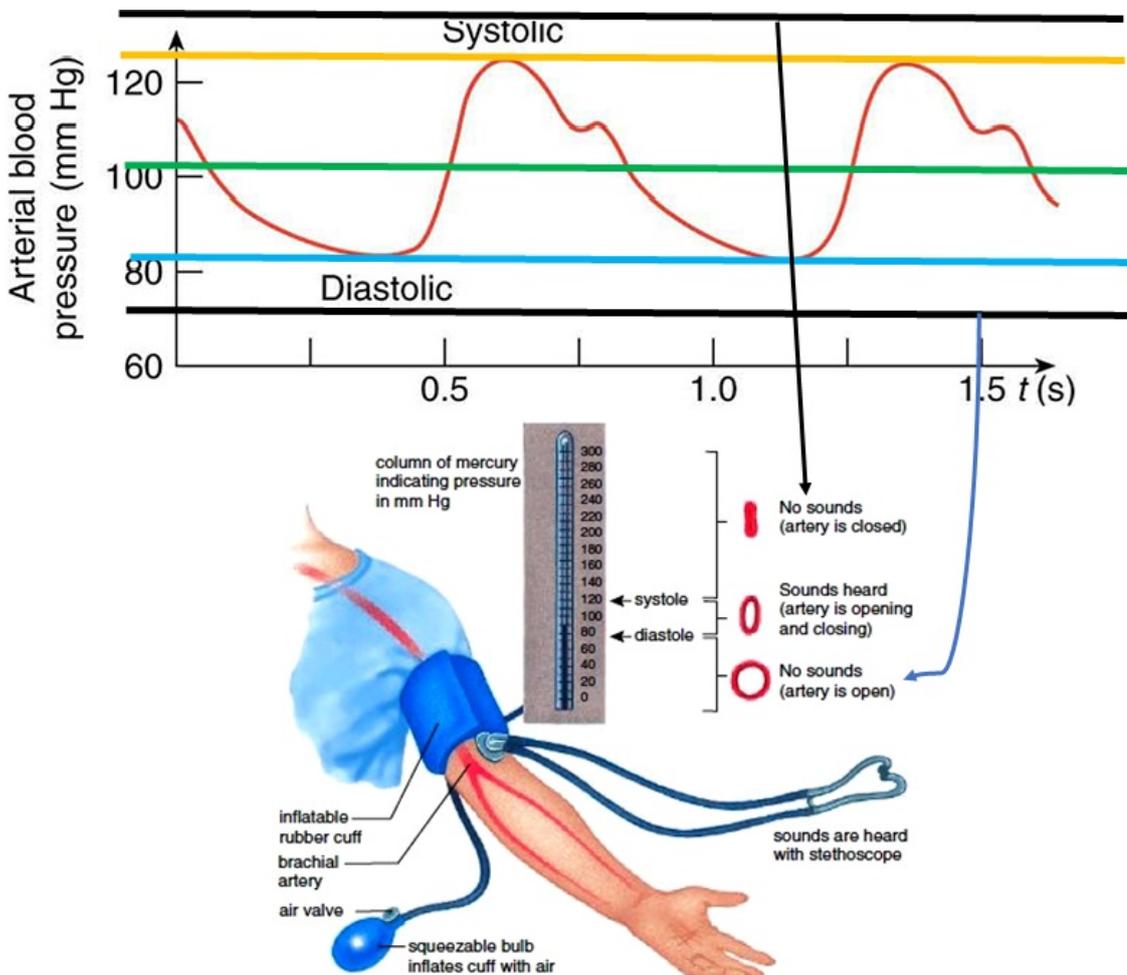
Systolic and Diastolic Pressures

- When systemic arterial blood pressure is measured, it is recorded as a ratio of two numbers (e.g., 120/80 is a normal adult blood pressure), expressed as systolic pressure over diastolic pressure.
- The systolic pressure is the higher value (typically around 120 mm Hg) and reflects the arterial pressure resulting from the ejection of blood during ventricular contraction, or systole.
- The diastolic pressure is the lower value (usually about 80 mm Hg) and represents the arterial pressure of blood during ventricular relaxation, or diastole.
- Arterial blood pressure in the larger vessels varies between systolic and diastolic pressures.
- Pulse pressure (PP) and mean arterial pressure (MAP) are calculated values based upon the systolic and diastolic pressures
 $PP = SBP - DBP$, $MAP = 1/3(SBP - DBP) + DBP$

23 / 57



The Physics of Sphygmomanometer



24 / 57



The Physics of Sphygmomanometer I

A sphygmomanometer is a device that measures blood pressure.

- It is composed of an inflatable rubber cuff, which is wrapped around the arm.
- A measuring device indicates the cuff's pressure.
- A bulb inflates the cuff and a valve releases pressure.
- A stethoscope is used to listen to arterial blood flow sounds.

As the heart beats, blood forced through the arteries cause a rise in pressure, called systolic pressure, followed by a decrease in pressure as the heart's ventricles prepare for another beat. This low pressure is called the diastolic pressure

The sphygmomanometer cuff is inflated to well above expected systolic pressure. As the valve is opened, cuff pressure (slowly) decreases. When the cuff's pressure equals the arterial systolic pressure, *blood begins to flow past the cuff, creating blood flow turbulence and audible sounds.*

25 / 57



The Physics of Sphygmomanometer II

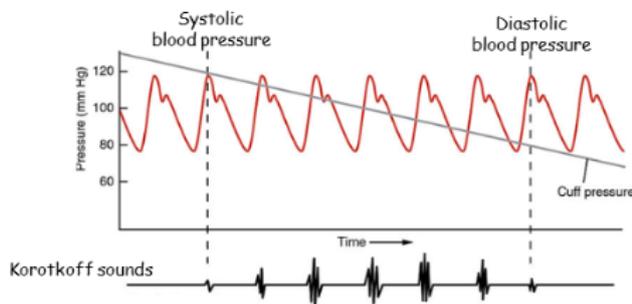
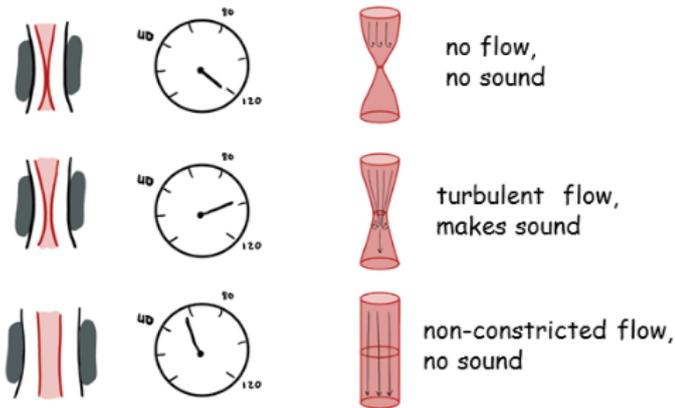
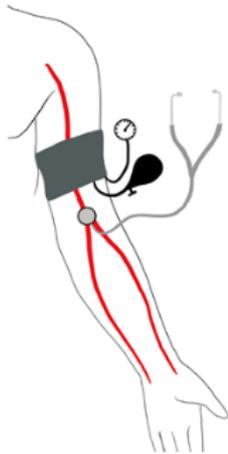
Using a stethoscope, these sounds are heard and the cuff's pressure is recorded. The blood flow sounds will continue until the cuff's pressure falls below the arterial diastolic pressure. The pressure when the blood flow sounds stop indicates the diastolic pressure.

Systolic and diastolic pressures are commonly stated as systolic 'over' diastolic. For example, 120 over 80. Blood flow sounds are called Korotkoff sounds

26 / 57



The Physics of Sphygmomanometer



27 / 57

Problem 24

The drawing shows an intravenous feeding. With the distance shown, nutrient solution ($\rho = 1030 \text{ kg/m}^3$) can just barely enter the blood in the vein. What is the gauge pressure of the venous blood? Express your answer in millimeters of mercury.



Problem 24

28 / 57

Problem 25

The human lungs can function satisfactorily up to a limit where the pressure difference between the outside and inside of the lungs is one-twentieth of an atmosphere. If a diver uses a snorkel for breathing, how far below the water can she swim? Assume the diver is in salt water whose density is ($\rho = 1025 \text{ kg/m}^3$)



29 / 57

Pascal's principle

Pascal's principle

A pressure change applied to an enclosed liquid is transmitted undiminished to every point in the liquid and to the walls of the container

Application: Hydraulic lift

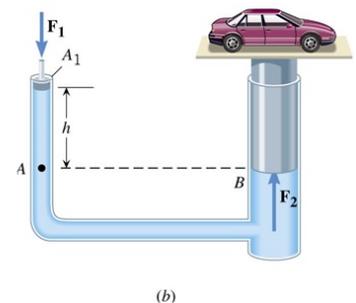
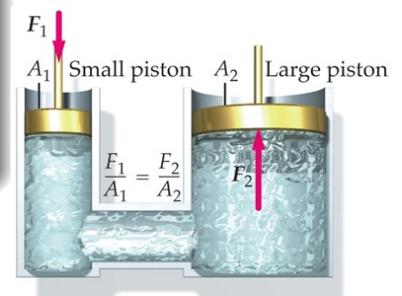
$$P_2 = P_1 + \rho gh$$

As long as the two pistons are at the same level

$$P_2 = P_1, \rho gh = 0$$

$$\frac{F_2}{A_2} = \frac{F_1}{A_1}$$

Multiplication of force can be achieved



30 / 57

Question 6

A cylinder is completely filled with water. The top of the cylinder is sealed with a tight-fitting lid. If you push down on the lid with a pressure of 1000 Pa, the water pressure at the bottom of the cylinder

- A increases by more than 1000 Pa
- B increases by 1000 Pa
- C increases by less than 1000 Pa
- D is unchanged
- E answer depends on the height of the cylinder

31 / 57

Question 7

According to Pascal's principle, the pressure at every point in a confined liquid

- A depends only on the density of the liquid.
- B is equal to the weight of the liquid.
- C is the same.
- D is changed the same amount by an externally applied pressure.
- E is equal to the externally applied pressure.

32 / 57

Problem 33

The atmospheric pressure above a swimming pool changes from 755 to 765 mm of mercury. The bottom of the pool is a rectangle ($12\text{ m} \times 24\text{ m}$). By how much does the force on the bottom of the pool increase?

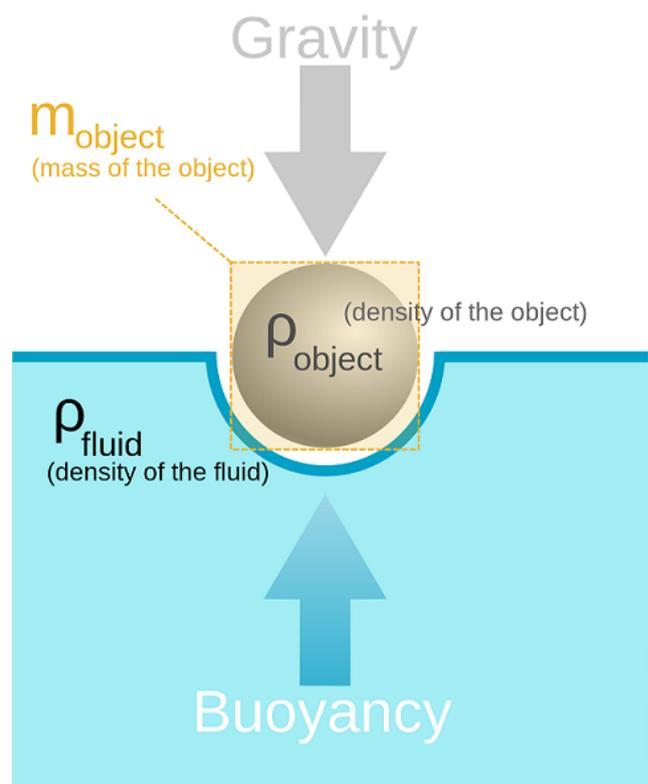
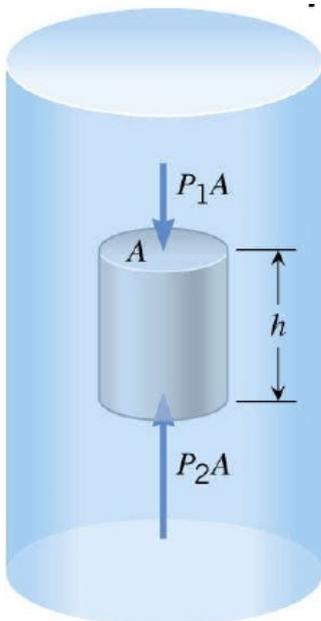
33 / 57

Archimedes' Principle

Buoyant Force: The buoyant force is the upward force exerted by a fluid on any immersed object

$$F_B = F_2 - F_1$$

$$F_B = P_2A - P_1A = \rho_f ghA = m_f g$$



34 / 57

Archimedes' Principle

Archimedes's Principle

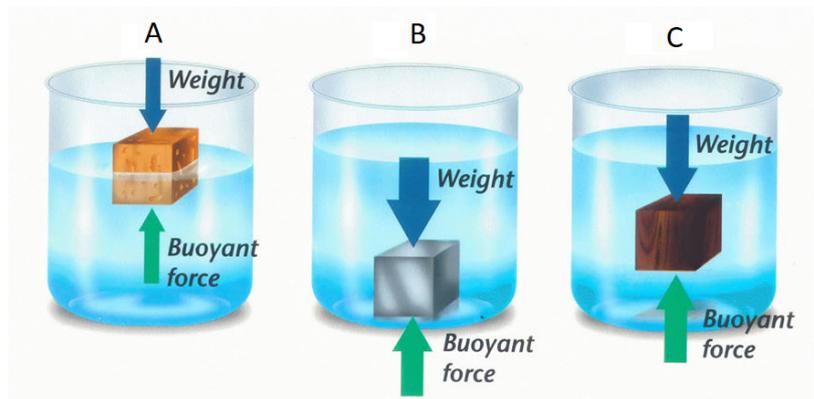
The magnitude of the buoyant force always equals the weight of the fluid displaced by the object.

- Archimedes's Principle does not refer to the makeup of the object experiencing the buoyant force
- The object's composition is not a factor since the buoyant force is exerted by the fluid

(A) Floating: Object density is less than fluid density

(B) Sinking: Object density is greater than fluid density

(C) Naturally buoyant: Object average density is equal to the fluid density



35 / 57

Archimedes' Principle

Totally Submerged Object:

Volume of displaced fluid (V_{fluid}) = volume of the object (V_{object})

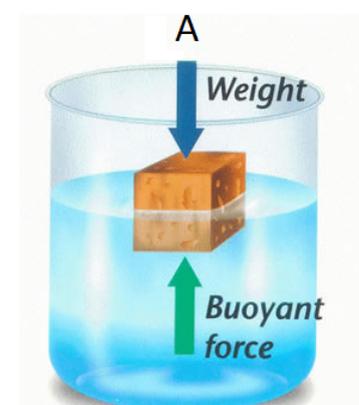
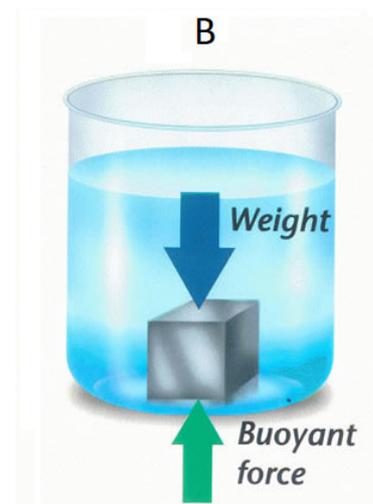
Floating Object:

- The object is in static equilibrium
- The upward buoyant force is balanced by the downward force of gravity
- Volume of the fluid displaced is less than the volume of the object

$$F_B = m_{ob}g = m_f g$$

$$\rho_{fluid} V_{fluid} g = \rho_{object} V_{object} g$$

$$\rho_{fluid} V_{fluid} = \rho_{object} V_{object}$$



36 / 57

Archimedes' Principle

What fraction of the iceberg is below water?

The iceberg is only partially submerged and so

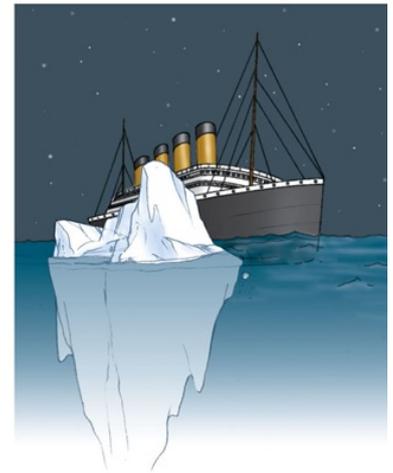
$$\frac{V_{\text{seawater}}}{V_{\text{ice}}} = \frac{\rho_{\text{ice}}}{\rho_{\text{seawater}}}$$

applies The fraction below the water will be the ratio of the volumes

$$\frac{V_{\text{seawater}}}{V_{\text{ice}}}$$

A Titanic Surprise

Only a small part of an iceberg protrudes above the water, while the bulk lies below the surface. The density of ice is 917 kg/m^3 and that of seawater is 1025 kg/m^3 . find the percentage of the iceberg's volume that lies below the surface.



(b)

© 2007 Thomson Higher Education

A ship can be

damaged even when it is not near the visible ice.

37 / 57

Question 8

A block of ice (density 920 kg/m^3) and a block of iron (density 7800 kg/m^3) are both submerged in a fluid. Both blocks have the same volume. Which block experiences the greater buoyant force?

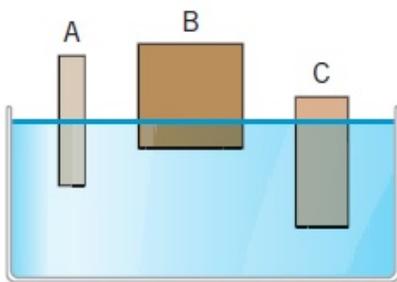
- A the block of ice
- B the block of iron
- C both experience the same buoyant force
- D answer depends on the density of the fluid

38 / 57

Focus on Concepts 10

Three solid objects are floating in a liquid, as in the drawing. They have different weights and volumes, but have the same thickness (the dimension perpendicular to the page). Rank the objects according to their density, largest first.

- (A) A, B, C
- (B) A, C, B
- (C) B, A, C
- (D) B, C, A
- (E) C, A, B



39 / 57

Check Your Understanding 8

A glass is filled to the brim with water and has an ice cube floating in it. When the ice cube melts, what happens? (a) Water spills out of the glass. (b) The water level in the glass drops. (c) The water level in the glass does not change.

Check Your Understanding 9

A steel beam is suspended completely under water by a cable that is attached to one end of the beam, so it hangs vertically. Another identical beam is also suspended completely under water, but by a cable that is attached to the center of the beam, so it hangs horizontally. Which beam, if either, experiences the greater buoyant force? Neglect any change in water density with depth.

40 / 57

Check Your Understanding 10

A glass beaker, filled to the brim with water, is resting on a scale. A solid block is then placed in the water, causing some of it to spill over. The water that spills is wiped away, and the beaker is still filled to the brim. How do the initial and final readings on the scale compare if the block is made from (a) wood (whose density is less than that of water) and (b) iron (whose density is greater than that of water)?

Check Your Understanding 11

On a distant planet the acceleration due to gravity is less than it is on earth. Would you float more easily in water on this planet than on earth?

41 / 57

Check Your Understanding 12

As a person dives toward the bottom of a swimming pool, the pressure increases noticeably. Does the buoyant force acting on her also increase? Neglect any change in water density with depth.

Check Your Understanding 13

A pot is partially filled with water, in which a plastic cup is floating. Inside the floating cup is a small block of lead. When the lead block is removed from the cup and placed into the water, it sinks to the bottom. When this happens, does the water level in the pot (a) rise, (b) fall, or (c) remain the same?

42 / 57

Problem 40

The density of ice is 917 kg/m^3 , and the density of seawater is 1025 kg/m^3 . A swimming polar bear climbs onto a piece of floating ice that has a volume of 5.2 m^3 . What is the weight of the heaviest bear that the ice can support without sinking completely beneath the water?

43 / 57

Problem 43

A duck is floating on a lake with 25% of its volume beneath the water. What is the average density of the duck?

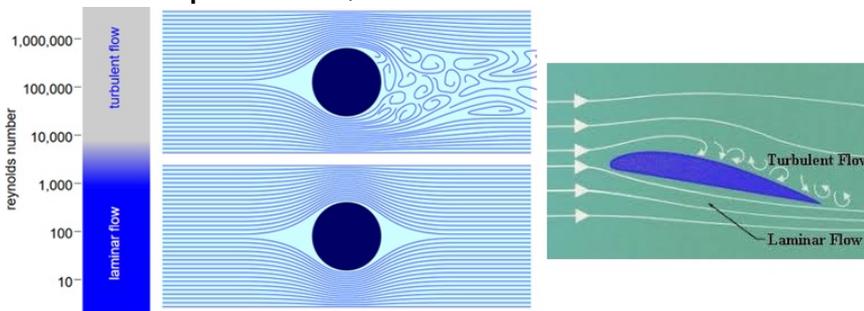
44 / 57

Fluids in motion (Fluid dynamics)

To describe the motion of a real fluid we make some assumptions. And many features of real fluids in motion can be understood by considering the behavior of an ideal fluid

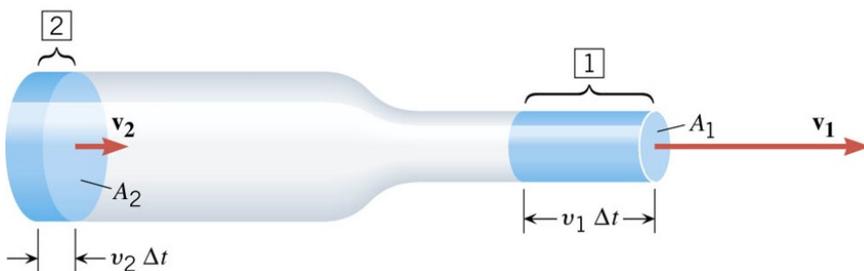
- Fluids flow can be steady or unsteady. In steady flow, the velocity of the fluid at each point remains constant in time
- Fluid flow can be compressible or incompressible where the density of the fluid remains constant in time
- Fluid flow can be viscous or nonviscous. In a nonviscous fluid the internal friction is neglected

An incompressible, nonviscous fluid is an ideal fluid



45 / 57

The equation of continuity



A fluid flowing in a tube that has different cross sectional areas

We assume that the fluid is incompressible

Mass flow rate at position 2 = mass flow rate at position 1

$$\frac{\Delta m_2}{\Delta t} = \frac{\Delta m_1}{\Delta t} = \frac{\rho \Delta V_2}{\Delta t} = \frac{\rho \Delta V_1}{\Delta t}$$

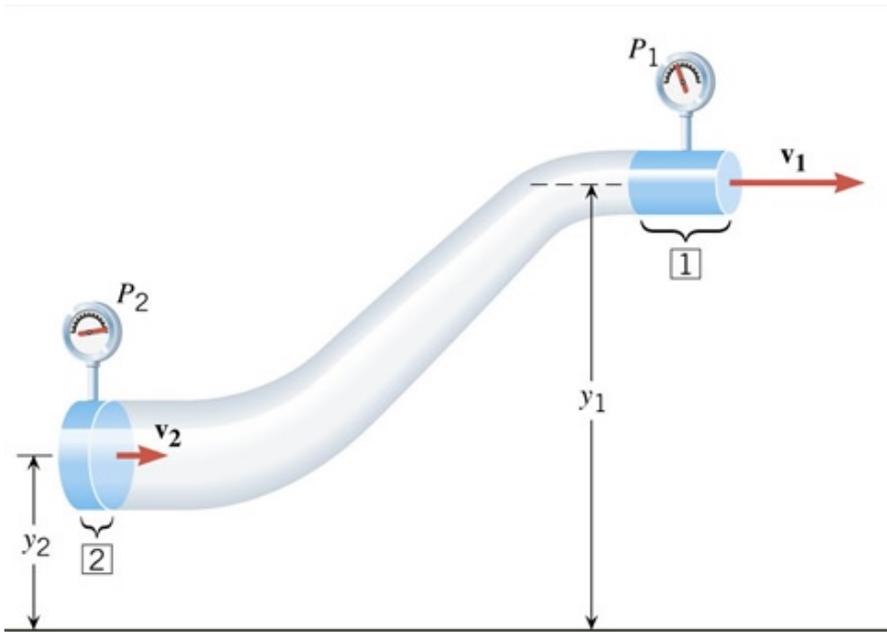
$$A_2 v_2 = A_1 v_1 = \text{constant}$$

v is the fluid speed

$Q = Av$, is called the volume flow rate

46 / 57

Bernoulli's equation and applications



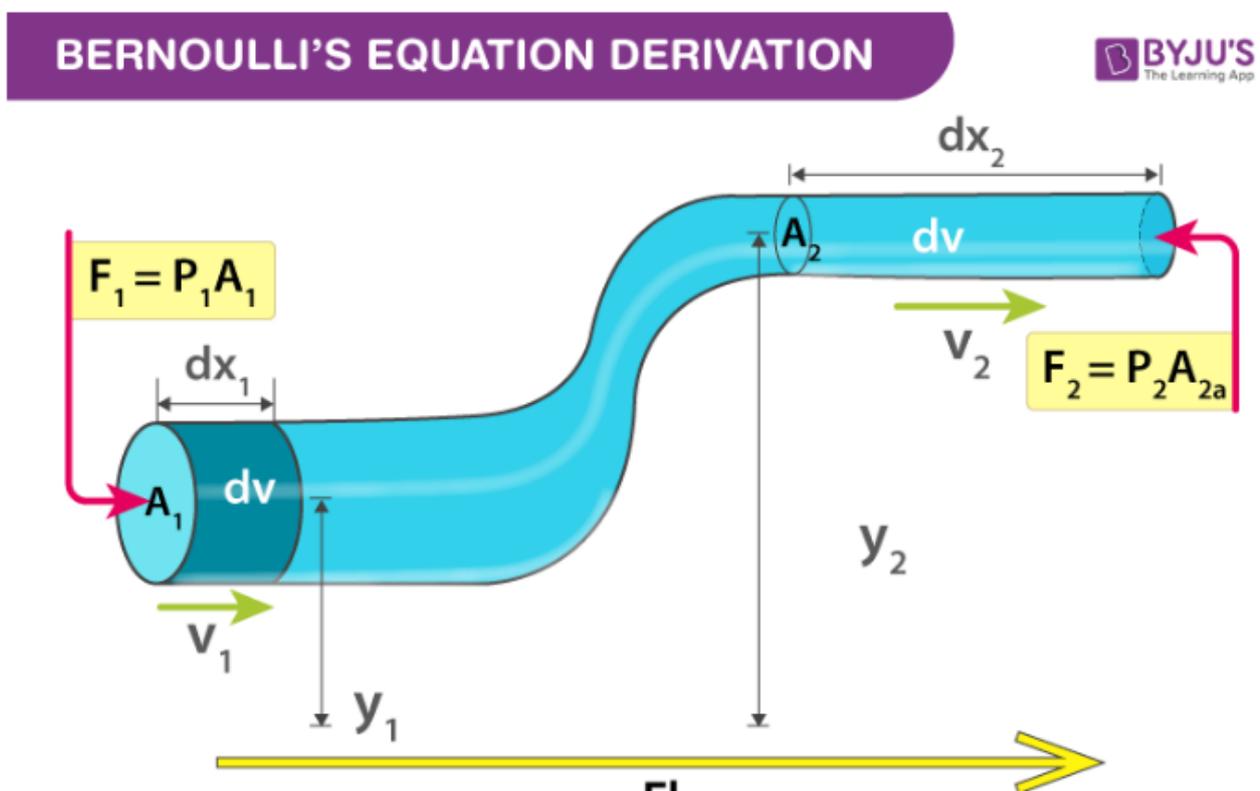
Fluid moving in a pipe that varies in both height and cross sectional area. Bernoulli's equation relates the pressure, elevation, and speed of an incompressible fluid in steady flow

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 = \text{constant}$$

Bernoulli's equation and applications

Bernoulli's Equation Derivation

Consider a pipe with varying diameter and height through which an incompressible fluid is flowing. The relationship between the areas of cross-sections A , the flow speed v , height from the ground y , and pressure p at two different points 1 and 2 is given in the figure below.



Bernoulli's equation and applications

Therefore, the work done on the fluid is given as:

$$dW = F_1 dx_1 - F_2 dx_2$$

$$dW = p_1 A_1 dx_1 - p_2 A_2 dx_2$$

$$dW = p_1 dV - p_2 dV = (p_1 - p_2) dV$$

We know that the work done on the fluid was due to conservation of gravitational force and change in kinetic energy. The change in kinetic energy of the fluid is given as:

$$dK = \frac{1}{2} m_2 v_2^2 - \frac{1}{2} m_1 v_1^2 = \frac{1}{2} \rho dV (v_2^2 - v_1^2)$$

The change in potential energy is given as:

$$dU = mgy_2 - mgy_1 = \rho dV g (y_2 - y_1)$$

Therefore, the energy equation is given as:

$$dW = dK + dU$$

$$(p_1 - p_2) dV = \frac{1}{2} \rho dV (v_2^2 - v_1^2) + \rho dV g (y_2 - y_1)$$

$$(p_1 - p_2) = \frac{1}{2} \rho (v_2^2 - v_1^2) + \rho g (y_2 - y_1)$$

Rearranging the above equation, we get

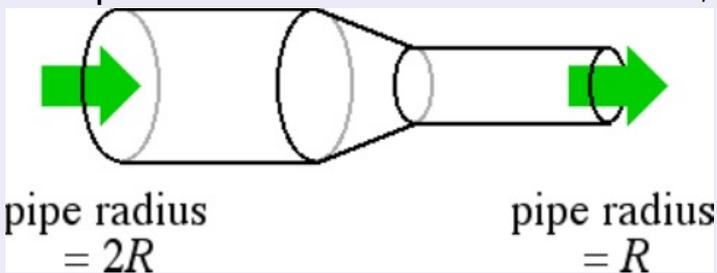
$$p_1 + \frac{1}{2} \rho v_1^2 + \rho g y_1 = p_2 + \frac{1}{2} \rho v_2^2 + \rho g y_2$$

This is Bernoulli's equation.

49 / 57

Question 9

An incompressible fluid flows through a pipe of varying radius as shown. Compared to the end with radius $2R$, the end with radius R has



- (A) 4 times the fluid speed and the same volume flow rate
- (B) 2 times the fluid speed and the same volume flow rate
- (C) the same fluid speed and 4 times the volume flow rate
- (D) the same fluid speed and 2 times the volume flow rate
- (E) none of the above

50 / 57

Problem 55

A patient recovering from surgery is being given fluid intravenously. The fluid has a density of 1030 kg/m^3 , and $9.5 \times 10^{-4} \text{ m}^3$ of it flows into the patient every six hours. Find the mass flow rate in kg/s .

51 / 57

Problem 56

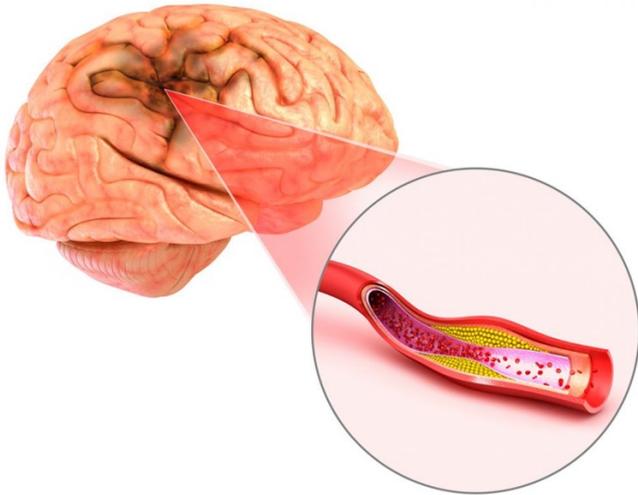
- (a) The volume flow rate in an artery supplying the brain is $3.6 \times 10^{-6} \text{ m}^3/\text{s}$. If the radius of the artery is 5.2 mm, determine the average blood speed.
- (b) Find the average blood speed at a constriction in the artery if the constriction reduces the radius by a factor of 3. Assume that the volume flow rate is the same as that in part (a).

52 / 57



The Physics of an Enlarged Blood Vessel.

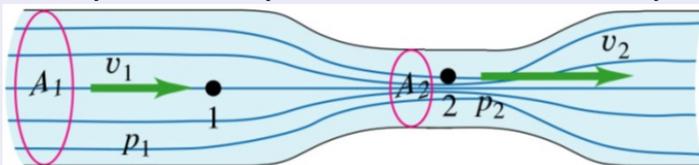
(An aneurysm is an abnormal enlargement of a blood vessel such as the aorta. Because of an aneurysm, the normal cross-sectional area A_1 of the aorta increases to a value of $A_2 = 1.7A_1$. The speed of the blood ($\rho = 1060\text{kg}/\text{m}^3$) through a normal portion of the aorta is $v_1 = 0.40\text{ m/s}$. Assuming that the aorta is horizontal (the person is lying down), determine the amount by which the pressure P_2 in the enlarged region exceeds the pressure P_1 in the normal region.



53 / 57

Question 10

An incompressible fluid flows through a pipe of varying radius as shown. Compared to point 1, the fluid at point 2 has



- (A) greater pressure and greater volume flow rate
- (B) greater pressure and the same volume flow rate
- (C) the same pressure and greater volume flow rate
- (D) lower pressure and the same volume flow rate
- (E) none of the above

54 / 57

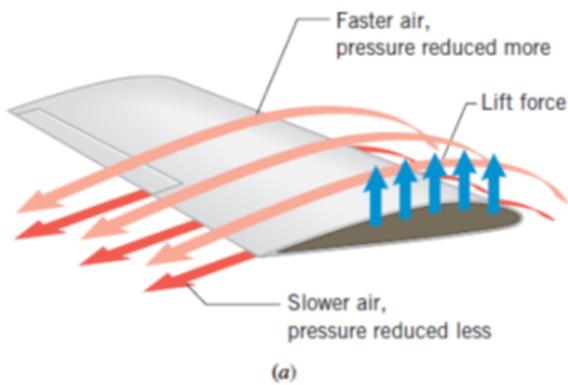
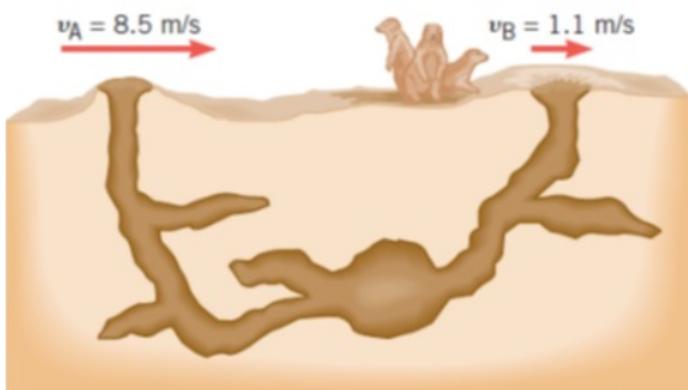


Figure 11.32 (a) Air flowing around an airplane wing. The wing is moving to the right. (b) The end of this wing has roughly the shape indicated in part a. (b. © Joe McBride/Getty Images)

Problem 61

Prairie dogs are burrowing rodents. They do not suffocate in their burrows, because the effect of air speed on pressure creates sufficient air circulation. The animals maintain a difference in the shapes of two entrances to the burrow, and because of this difference, the air ($\rho = 1.29 \text{ kg/m}^3$) blows past the openings at different speeds, as the drawing indicates. Assuming that the openings are at the same vertical level, find the difference in air pressure between the openings and indicate which way the air circulates.



Homework Problems: 26, 27, 44, 49, 59, 66, 69

The End

Temperature and Heat (Chapter 12)

- 1 Common Temperature Scales
- 2 The Kelvin Temperature Scale
- 3 Thermometers
- 4 Linear Thermal Expansion
- 5 Volume Thermal Expansion
- 6 Heat and Internal Energy
- 7 Specific Heat Capacity
- 8 Heat and Phase Change: Latent Heat
- 9 Equilibrium Between Phases of Matter

1 / 56

It is easy to trick our sense of temperature

Temperature, measure of hotness or coldness expressed in terms of any of several arbitrary scales and indicating the direction in which heat energy will spontaneously flow—i.e., from a hotter body (one at a higher temperature) to a colder body (one at a lower temperature).

Temperature is not the equivalent of the energy of a thermodynamic system; e.g., a burning match is at a much higher temperature than an iceberg, but the total heat energy contained in an iceberg is much greater than the energy contained in a match.



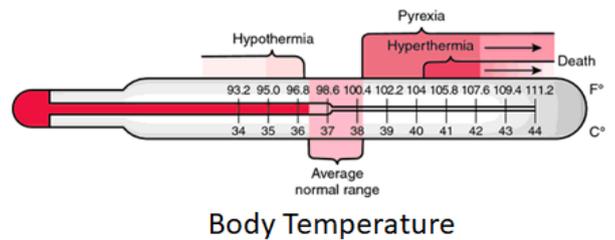
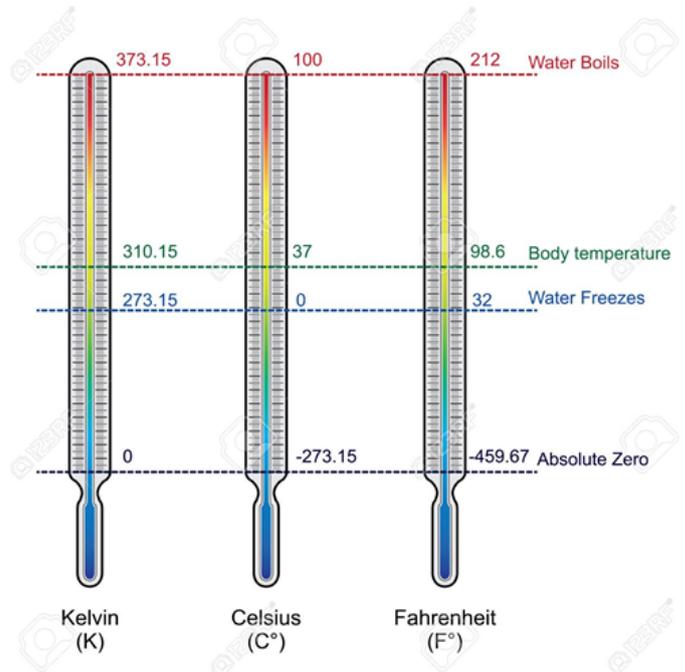
2 / 56

Common Temperature Scales

The conversion formula for a temperature that is expressed on the Celsius (C) scale to its Fahrenheit (F) representation is: $F = 9/5C + 32$.

The following formula can be used to convert a temperature from its representation on the Fahrenheit (F) scale to the Celsius (C) value: $C = 5/9(F - 32)$.

Kelvin temperature scale is the base unit of thermodynamic temperature measurement in the International System (SI) of measurement.
 $T = T_c + 273.15$



Absolute Temperature

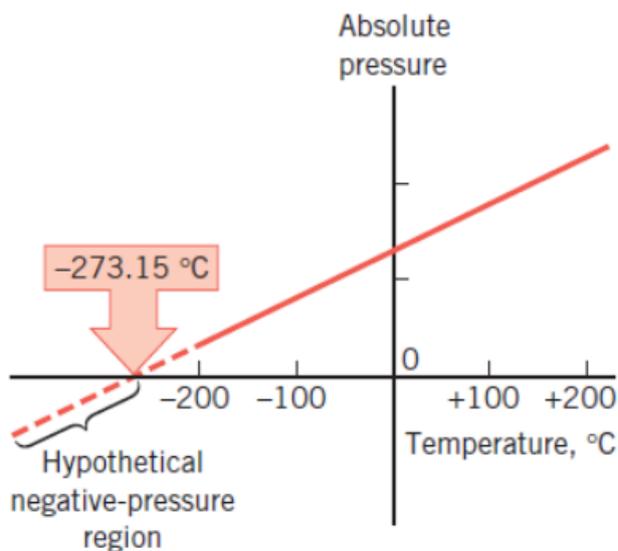


Figure 12.4 A plot of absolute pressure versus temperature for a low-density gas at constant volume. The graph is a straight line and, when extrapolated (dashed line), crosses the temperature axis at $-273.15\text{ }^\circ\text{C}$.

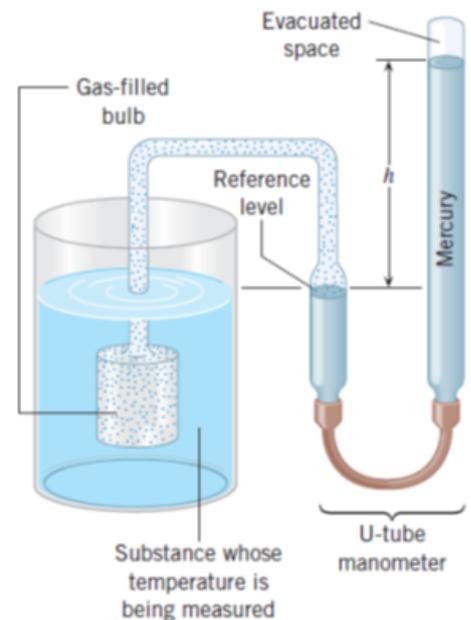


Figure 12.3 A constant-volume gas thermometer.

Absolute Temperature

- The value of 273.15 C has fundamental significance. The significance of this number is that it is the absolute zero point for temperature measurement.
- The phrase “absolute zero” means that temperatures lower than 273.15 C cannot be reached by continually cooling a gas or any other substance.
- If lower temperatures could be reached, then further extrapolation of the straight line in Figure 12.4 would suggest that negative absolute gas pressures could exist.
- Such a situation would be impossible, because a negative absolute gas pressure has no meaning.
- Thus, the Kelvin scale is chosen so that its zero temperature point is the lowest temperature attainable

5 / 56

Problem 5

Dermatologists often remove small precancerous skin lesions by freezing them quickly with liquid nitrogen, which has a temperature of 77 K. What is this temperature on the (a) Celsius and (b) Fahrenheit scales?

6 / 56

Thermometers

A thermometer is a device that is used to measure the temperature of a system

Thermometers are based on the principle that some physical property of a system changes as the system's temperature changes

These properties include:

- The volume of a liquid
- The dimensions of a solid
- The pressure of a gas at a constant volume
- The volume of a gas at a constant pressure
- The electric resistance of a conductor
- The color of an object

A temperature scale can be established on the basis of any of these physical properties

7 / 56

The physics of thermography.

- The principle of infrared thermography is based on the physical phenomenon that any body of a temperature above absolute zero ($-273.15\text{ }^{\circ}\text{C}$) emits electromagnetic radiation.
- There is clear correlation between the surface of a body and the intensity and spectral composition of its emitted radiation.
- By determining its radiation intensity the temperature of an object can thereby be determined in a non-contact way.
- In one interesting application, an infrared camera registers the intensity of the infrared radiation produced at different locations on the human body.
- The camera is connected to a color monitor that displays the different infrared intensities as different colors. This "thermal painting" is called a thermograph or thermogram.
- Thermography is an important diagnostic tool in medicine. For example, breast cancer is indicated in the thermogram in Figure 12.6 by the elevated temperatures associated with malignant tissue.

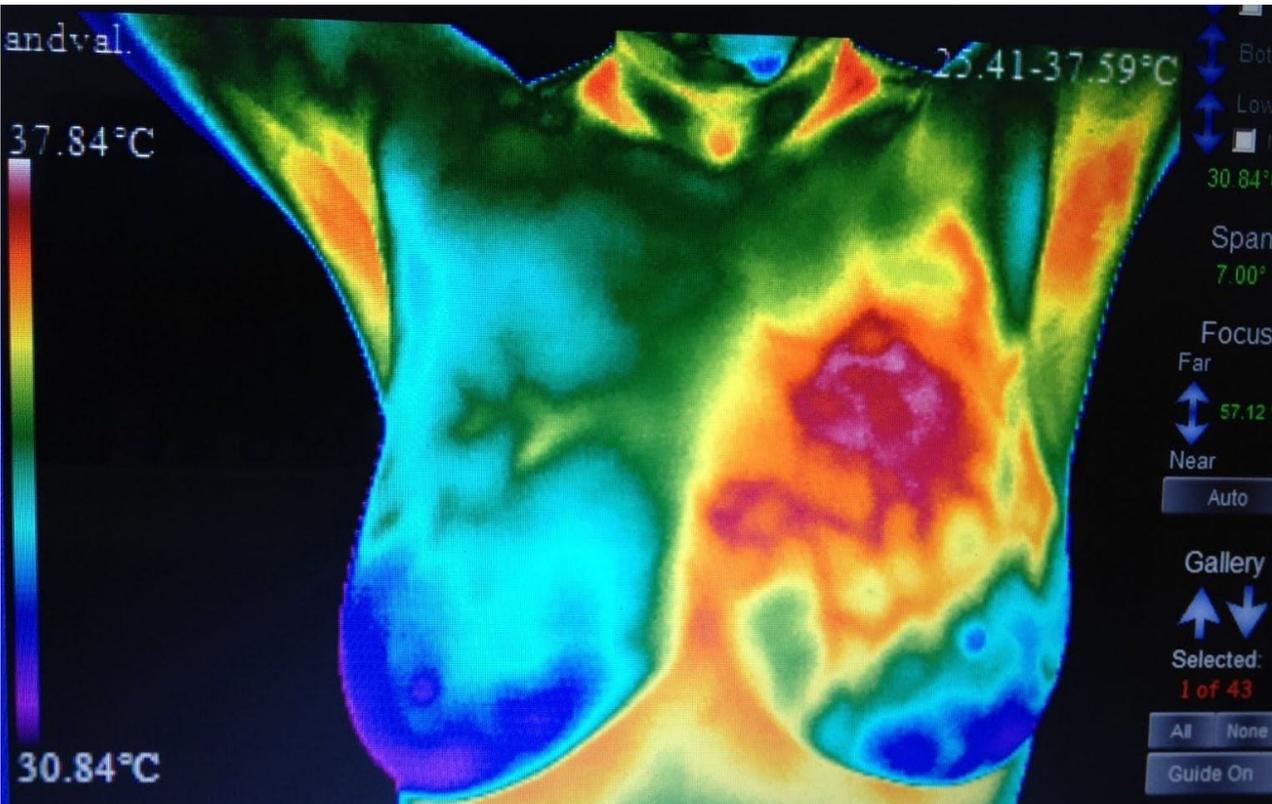
8 / 56

 The physics of thermography.



9 / 56

 The physics of thermography.

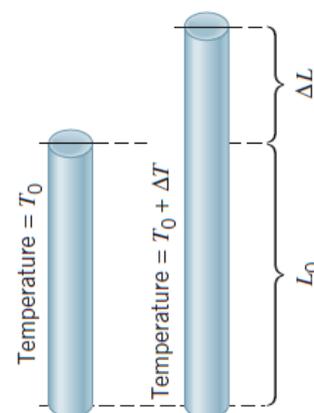


The U.S. Food and Drug Administration (FDA) consider that mammography (low-dose X-ray imaging of the breast) is still the most effective primary breast cancer screening test.

10 / 56

Thermal Expansion

- Thermal expansion is the increase in the size of an object with an increase in its temperature
- Thermal expansion is a consequence of the change in the average separation between the atoms in an object
- If the expansion is small relative to the original dimensions of the object, the change in any dimension is, to a good approximation, proportional to the first power of the change in temperature



Linear Expansion

Assume an object has an initial length L That length increases by ΔL as the temperature changes by ΔT We define the coefficient of linear expansion as A convenient form is

$$\Delta L = \alpha L_0 \Delta T$$

11 / 56

Coefficients Thermal Expansion.

Table 12.1 Coefficients of Thermal Expansion for Solids and Liquids^a

Substance	Coefficient of Thermal Expansion (C°) ⁻¹	
	Linear (α)	Volume (β)
<i>Solids</i>		
Aluminum	23×10^{-6}	69×10^{-6}
Brass	19×10^{-6}	57×10^{-6}
Concrete	12×10^{-6}	36×10^{-6}
Copper	17×10^{-6}	51×10^{-6}
Glass (common)	8.5×10^{-6}	26×10^{-6}
Glass (Pyrex)	3.3×10^{-6}	9.9×10^{-6}
Gold	14×10^{-6}	42×10^{-6}
Iron or steel	12×10^{-6}	36×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Nickel	13×10^{-6}	39×10^{-6}
Quartz (fused)	0.50×10^{-6}	1.5×10^{-6}
Silver	19×10^{-6}	57×10^{-6}
<i>Liquids^b</i>		
Benzene	—	1240×10^{-6}
Carbon tetrachloride	—	1240×10^{-6}
Ethyl alcohol	—	1120×10^{-6}
Gasoline	—	950×10^{-6}
Mercury	—	182×10^{-6}
Methyl alcohol	—	1200×10^{-6}
Water	—	207×10^{-6}

^aThe values for α and β pertain to a temperature near 20 °C.

^bSince liquids do not have fixed shapes, the coefficient of linear expansion is not defined for them.

12 / 56

Bimetallic Strip

Each substance has its own characteristic average coefficient of expansion
Applications: a bimetallic strip, it can be used in a thermostat

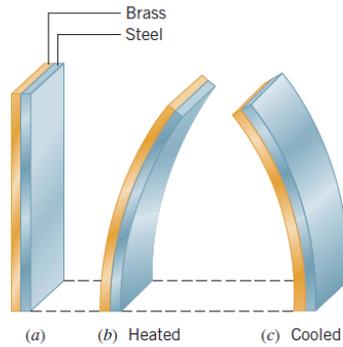
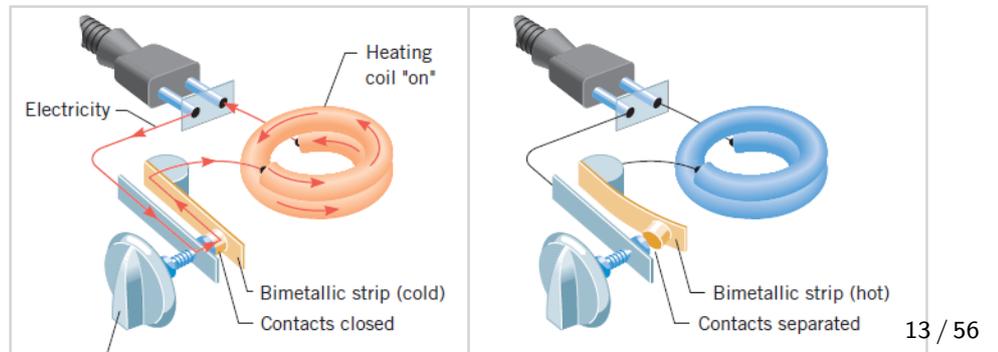
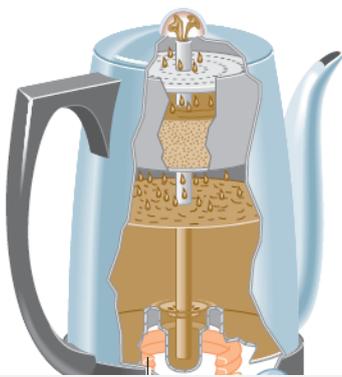


Figure 12.15 (a) A bimetallic strip and how it behaves when (b) heated and (c) cooled.

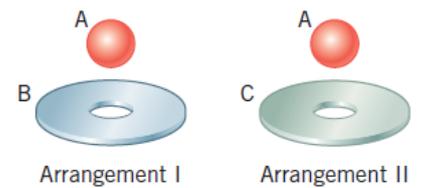


Problem 10

A steel section of the Alaskan pipeline had a length of 65 m and a temperature of $18\text{ }^{\circ}\text{C}$ when it was installed. What is its change in length when the temperature drops to a frigid $45\text{ }^{\circ}\text{C}$?

Focus on concepts 4

A ball is slightly too large to fit through a hole in a flat plate. The drawing shows two arrangements of this situation. In Arrangement I the ball is made from metal A and the plate from metal B. When both the ball and the plate are cooled by the same number of Celsius degrees, the ball passes through the hole.



In Arrangement II the ball is also made from metal A, but the plate is made from metal C. Here, the ball passes through the hole when both the ball and the plate are heated by the same number of Celsius degrees. Rank the coefficients of linear thermal expansion of metals A, B, and C in descending order (largest first):

- A $\alpha_B, \alpha_A, \alpha_C$
- B $\alpha_B, \alpha_C, \alpha_A$
- C $\alpha_C, \alpha_B, \alpha_A$
- D $\alpha_C, \alpha_A, \alpha_B$
- E $\alpha_A, \alpha_B, \alpha_C$

15 / 56

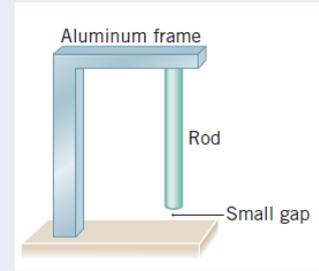
Problem 15

When the temperature of a coin is raised by $75\text{ }^\circ\text{C}$, the coin's diameter increases by $2.3 \times 10^{-5}\text{ m}$. If the original diameter of the coin is $1.8 \times 10^{-2}\text{ m}$, find the coefficient of linear expansion.

16 / 56

Check Your Understanding 2

A rod is hung from an aluminum frame, as the drawing shows. The rod and the frame have the same temperature, and there is a small gap between the rod and the floor. The frame and rod are then heated uniformly. Will the rod ever touch the floor if the rod is made from (a) aluminum, (b) lead, (c) brass?



Check Your Understanding 4

For added strength, many highways and buildings are constructed with reinforced concrete (concrete that is reinforced with embedded steel rods). Table 12.1 shows that the coefficient of linear expansion α for concrete is the same as that for steel. Why is it important that these two coefficients be the same?

17 / 56

Check Your Understanding 5

One type of cooking pot is made from stainless steel and has a copper coating over the outside of the bottom. At room temperature the bottom of this pot is flat, but when heated the bottom is not flat. When the bottom of this pot is heated, is it bowed outward or inward?

Check Your Understanding 6

A metal ball has a diameter that is slightly greater than the diameter of a hole that has been cut into a metal plate. The coefficient of linear expansion for the metal from which the ball is made is greater than that for the metal of the plate. Which one or more of the following procedures can be used to make the ball pass through the hole? (a) Raise the temperatures of the ball and the plate by the same amount. (b) Lower the temperatures of the ball and the plate by the same amount. (c) Heat the ball and cool the plate. (d) Cool the ball and heat the plate.

18 / 56

Check Your Understanding 7

A hole is cut through an aluminum plate. A brass ball has a diameter that is slightly smaller than the diameter of the hole. The plate and the ball have the same temperature at all times. Should the plate and ball both be heated or both be cooled to prevent the ball from falling through the hole?

19 / 56

Volume Thermal Expansion

The volume of a normal material increases as the temperature increases. Most solids and liquids behave in this fashion.

By analogy with linear thermal expansion, the change in volume V is proportional to the change in temperature T and to the initial volume V_0 , provided the change in temperature is not too large.

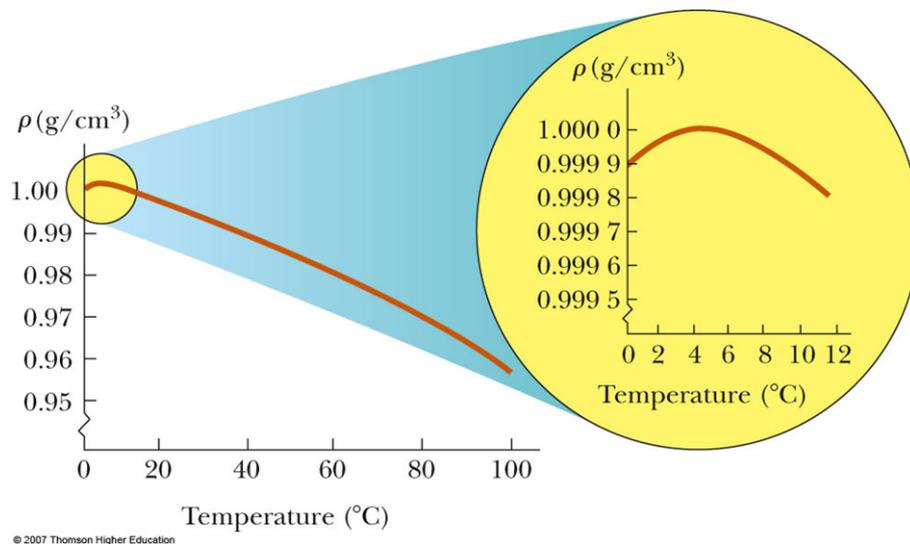
The change in volume is proportional to the original volume and to the change in temperature

$$\Delta V = \beta V_0 \Delta T$$

β is the coefficient of volume expansion For a solid, $\beta = 3\alpha$ This assumes the material is isotropic, the same in all directions

20 / 56

Water's Unusual Behavior



- As the temperature increases from 0 °C to 4 °C, water contracts Its density increases
- Above 4 °C, water expands with increasing temperature Its density decreases
- The maximum density of water (1.000 g/cm³) occurs at 4 °C

21 / 56

The physics of ice formation and the survival of aquatic life. I

The fact that water has its greatest density at 4 °C, rather than at 0 °C, has important consequences for the way in which a lake freezes.

- When the air temperature drops, the surface layer of water is chilled.
- As the temperature of the surface layer drops toward 4 °C, this layer becomes more dense than the warmer water below.
- The denser water sinks and pushes up the deeper and warmer water, which in turn is chilled at the surface.
- This process continues until the temperature of the entire lake reaches 4 °C.
- Further cooling of the surface water below 4 °C makes it less dense than the deeper layers; consequently, the surface layer does not sink but stays on top.

22 / 56

The physics of ice formation and the survival of aquatic life. II

- Continued cooling of the top layer to $0\text{ }^{\circ}\text{C}$ leads to the formation of ice that floats on the water, because ice has a smaller density than water at any temperature.
- Below the ice, however, the water temperature remains above $0\text{ }^{\circ}\text{C}$. The sheet of ice acts as an insulator that reduces the loss of heat from the lake, especially if the ice is covered with a blanket of snow, which is also an insulator.
- As a result, lakes usually do not freeze solid, even during prolonged cold spells, so fish and other aquatic life can survive.

23 / 56

Saint-Petersburg, Russia. On the frozen ice of Neva river.



24 / 56

Problem 28

A flask is filled with 1.500 L (L = liter) of a liquid at 97.1 °C. When the liquid is cooled to 15.0 °C, its volume is only 1.383 L, however. Neglect the contraction of the flask and use Table 12.1 to identify the liquid.

25 / 56

Problem 29

A thin spherical shell of silver has an inner radius of 2.0×10^{-2} m when the temperature is 18 °C. The shell is heated to 147 °C. Find the change in the interior volume of the shell.

26 / 56

Heat and Internal Energy I

Definition of Heat

Heat is energy that flows from a higher-temperature object to a lower-temperature object because of the difference in temperatures.

SI Unit of Heat: joule (J).

Internal Energy

Internal energy is all the energy of a system that is associated with its microscopic components

- These components are its atoms and molecules
- The system is viewed from a reference frame at rest with respect to the center of mass of the system

27 / 56

Heat and Internal Energy II

The kinetic energy due to its motion through space is not included Internal energy does include kinetic energies due to:

- Random translational motion
- Rotational motion
- Vibrational motion

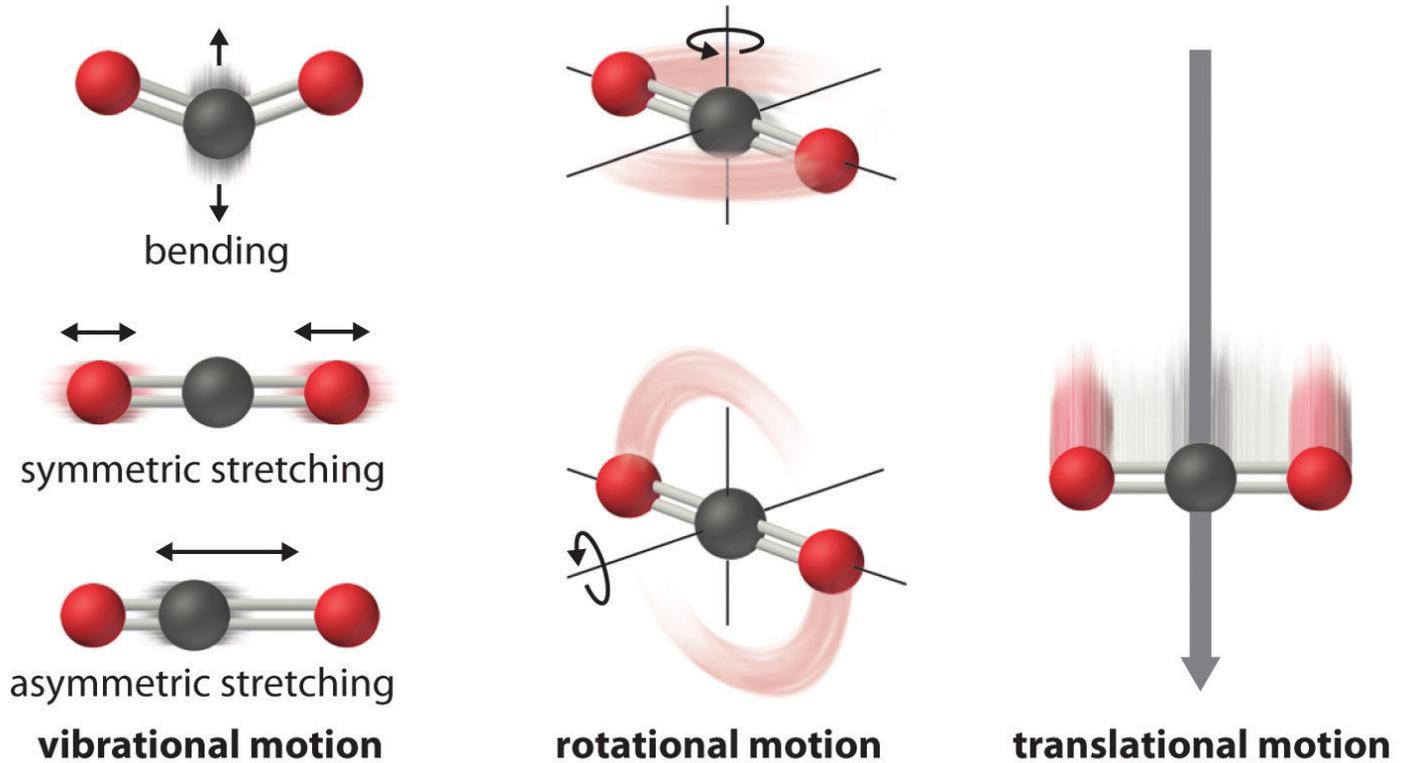
Internal energy also includes potential energy between molecules

Important Concept

it is not correct to say that a substance contains heat. The substance has internal energy, not heat. The word “heat” only refers to the energy actually in transit from hot to cold.

28 / 56

Heat and Internal Energy III



29 / 56

Heat and Temperature Change: Specific Heat Capacity

Different substances respond to heat in different ways.

- If a metal chair sits in the bright sun on a hot day, it may become quite hot to the touch.
- An equal mass of water in the same sun will not become nearly as hot.
- We would say that water has a high heat capacity (the amount of heat required to raise the temperature of an object by 1°C).
- Water is very resistant to changes in temperature, while metals in general are not.

The heat capacity, C , of a particular sample is defined as the amount of energy needed to raise the temperature of that sample by 1°C If energy Q produces a change of temperature of ΔT , then

$$Q = C\Delta T = mc\Delta T$$

C : heat capacity

c : specific heat capacity

30 / 56

Heat and Temperature Change: Specific Heat Capacity

Heat Units Other than the Joule

Calorie

One calorie is the amount of energy transfer necessary to raise the temperature of 1 g of water from 14.5 °C to 15.5 °C

The “Calorie” used for food is actually 1 kilocalorie

BTU

In the US Customary system, the unit is a BTU (British Thermal Unit)

One BTU is the amount of energy transfer necessary to raise the temperature of 1 lb of water from 63 °F to 64 °F

Joule

The joule is a derived unit of energy in the International System of Units.

1 Calorie = 4.186 Joules

31 / 56

Heat and Temperature Change: Specific Heat Capacity

Calorimetry:

One technique for measuring specific heat involves heating a material, adding it to a sample of water, and recording the final temperature

A calorimeter is a device in which this energy transfer takes place

Conservation of energy

Quantity of heat lost by the unknown material = Quantity of heat gained by the calorimeter

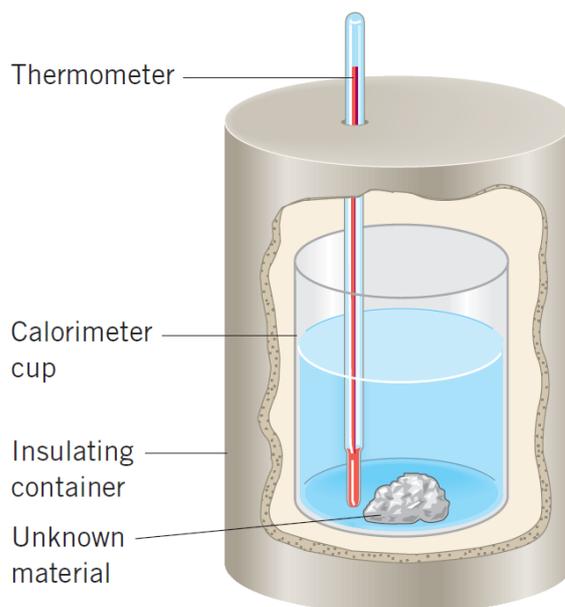


Figure 12.25 A calorimeter can be used to measure the specific heat capacity of an unknown material.

32 / 56

Nutrition facts label

Nutrition Facts	
8 servings per container	
Serving size	2/3 cup (55g)
Amount per 2/3 cup	
Calories	230
% DV*	
12%	Total Fat 8g
5%	Saturated Fat 1g
	<i>Trans Fat</i> 0g
0%	Cholesterol 0mg
7%	Sodium 160mg
12%	Total Carbs 37g
14%	Dietary Fiber 4g
	Sugars 1g
	Added Sugars 0g
	Protein 3g
10%	Vitamin D 2mcg
20%	Calcium 260mg
45%	Iron 8mg
5%	Potassium 235mg
* Footnote on Daily Values (DV) and calories reference to be inserted here.	

33 / 56

Focus on concepts 9

Which of the following cases (if any) requires the greatest amount of heat? In each case the material is the same.

- A 1.5 kg of the material is to be heated by $7.0\text{ }^{\circ}\text{C}$.
- B 3.0 kg of the material is to be heated by $3.5\text{ }^{\circ}\text{C}$.
- C 0.50 kg of the material is to be heated by $21\text{ }^{\circ}\text{C}$.
- D 0.75 kg of the material is to be heated by $14\text{ }^{\circ}\text{C}$.
- E The amount of heat required is the same in each of the four previous cases.

34 / 56

Check Your Understanding 10

Two different objects are supplied with equal amounts of heat. Which one or more of the following statements explain why their temperature changes would not necessarily be the same? (a) The objects have the same mass but are made from materials that have different specific heat capacities. (b) The objects are made from the same material but have different masses. (c) The objects have the same mass and are made from the same material.

Check Your Understanding 11

Two objects are made from the same material but have different masses. The two are placed in contact, and neither one loses any heat to the environment. Which object experiences the temperature change with the greater magnitude, or does each object experience a temperature change of the same magnitude?

35 / 56

Focus on concepts 10

The following three hot samples have the same temperature. The same amount of heat is removed from each sample. Which one experiences the smallest drop in temperature, and which one experiences the largest drop?

Sample A. 4.0 kg of water [$c = 4186 \text{ J}/(\text{kg}^\circ\text{C})$]

Sample B. 2.0 kg of oil [$c = 2700 \text{ J}/(\text{kg}^\circ\text{C})$]

Sample C. 9.0 kg of dirt [$c = 1050 \text{ J}/(\text{kg}^\circ\text{C})$]

- A C smallest and A largest
- B B smallest and C largest
- C A smallest and B largest
- D C smallest and B largest
- E B smallest and A largest

36 / 56

Problem 44

Blood can carry excess energy from the interior to the surface of the body, where the energy is dispersed in a number of ways. While a person is exercising, 0.6 kg of blood flows to the body's surface and releases 2000 J of energy. The blood arriving at the surface has the temperature of the body's interior, $37.0\text{ }^{\circ}\text{C}$. Assuming that blood has the same specific heat capacity as water, determine the temperature of the blood that leaves the surface and returns to the interior.

37 / 56

Problem 50

When you drink cold water, your body must expend metabolic energy in order to maintain normal body temperature ($37\text{ }^{\circ}\text{C}$) by warming up the water in your stomach. Could drinking ice water, then, substitute for exercise as a way to “burn calories?” Suppose you expend 430 kilocalories during a brisk hour-long walk. How many liters of ice water ($0\text{ }^{\circ}\text{C}$) would you have to drink in order to use up 430 kilocalories of metabolic energy? For comparison, the stomach can hold about 1 liter.

38 / 56

Heat and Phase Change: Latent Heat

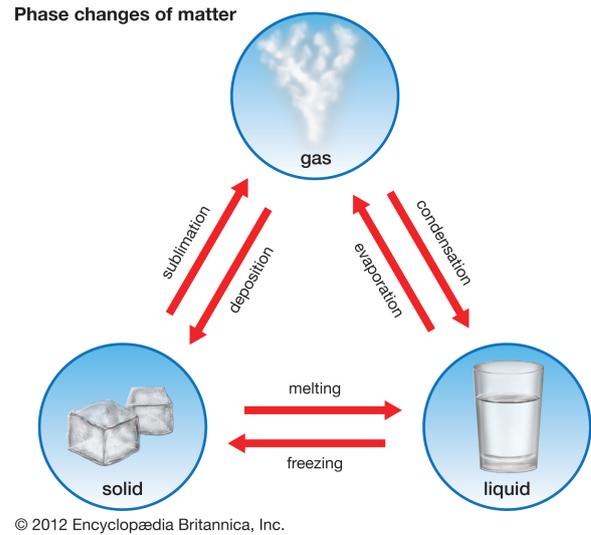
A phase change

is when a substance changes from one form to another

Two common phase changes are

- Solid to liquid (melting)
- Liquid to gas (boiling)

DURING A PHASE CHANGE, THERE IS NO CHANGE IN TEMPERATURE OF THE SUBSTANCE



For example, in boiling the increase in internal energy is represented by the breaking of the bonds between molecules, giving the molecules of the gas a higher intermolecular potential energy.

39 / 56

Heat and Phase Change: Latent Heat: Example

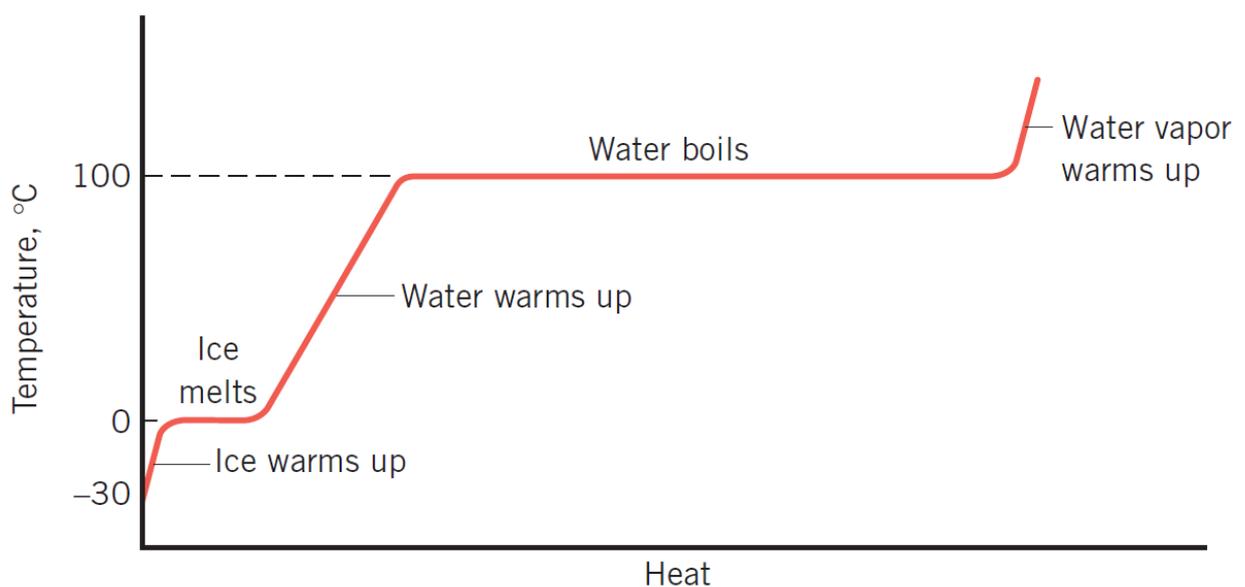


Figure: The graph shows the way the temperature of water changes as heat is added, starting with ice at 30 °C. The pressure is atmospheric pressure.

40 / 56

Conceptual Example:

Saving Energy

Suppose you are cooking spaghetti, and the instructions say “boil the pasta in water for ten minutes.” To cook spaghetti in an open pot using the least amount of energy, should you (a) turn up the burner to its fullest so the water vigorously boils or (b) turn down the burner so the water barely boils?

41 / 56

Latent Heat

Latent Heat

Latent heat is energy released or absorbed, by a body or a thermodynamic system, during a constant-temperature process — usually a first-order phase transition.

- Latent heat can be understood as energy in hidden form which is supplied or extracted to change the state of a substance without changing its temperature.
- Different substances react differently to the energy added or removed during a phase change Due to their different internal molecular arrangements
- The amount of energy also depends on the mass of the sample

42 / 56

Latent Heat

If an amount of energy Q is required to change the phase of a sample of mass m ,

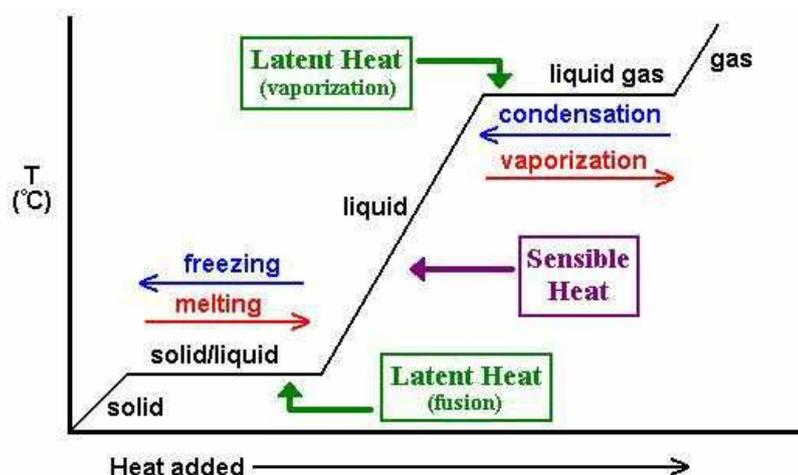
$$L = \frac{Q}{m}$$

- The quantity L is called the latent heat of the material
- Latent means **hidden**
- The value of L depends on the substance as well as the actual phase change
- The energy required to change the phase is $Q = \pm mL$

43 / 56

Latent Heat

- The latent heat of fusion is used when the phase change is from solid to liquid
- The latent heat of vaporization is used when the phase change is from liquid to gas
- The positive sign is used when the energy is transferred into the system. This will result in melting or boiling
- The negative sign is used when energy is transferred out of the system. This will result in freezing or condensation



44 / 56

Table 12.3 Latent Heats^a of Fusion and Vaporization

Substance	Melting Point (°C)	Latent Heat of Fusion, L_f (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization, L_v (J/kg)
Ammonia	-77.8	33.2×10^4	-33.4	13.7×10^5
Benzene	5.5	12.6×10^4	80.1	3.94×10^5
Copper	1083	20.7×10^4	2566	47.3×10^5
Ethyl alcohol	-114.4	10.8×10^4	78.3	8.55×10^5
Gold	1063	6.28×10^4	2808	17.2×10^5
Lead	327.3	2.32×10^4	1750	8.59×10^5
Mercury	-38.9	1.14×10^4	356.6	2.96×10^5
Nitrogen	-210.0	2.57×10^4	-195.8	2.00×10^5
Oxygen	-218.8	1.39×10^4	-183.0	2.13×10^5
Water	0.0	33.5×10^4	100.0	22.6×10^5

^aThe values pertain to 1 atm pressure.

Conceptual Example: The physics of steam burns.

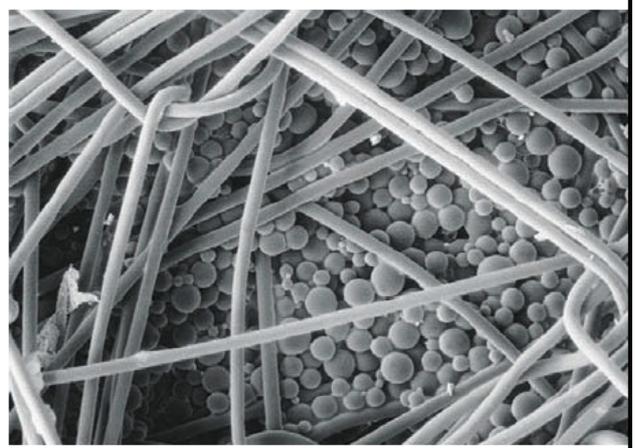
In comparison to the latent heat of fusion, Table 12.3 indicates that the latent heat of vaporization for water has the much larger value of $L_v = 22.6 \times 10^5$ J/ kg.

- When water boils at 100°C , 22.6×10^5 J of heat must be supplied for each kilogram of liquid turned into steam.
- And when steam condenses at 100°C , this amount of heat is released from each kilogram of steam that changes back into liquid.
- Liquid water at 100°C is hot enough by itself to cause a bad burn, and the additional effect of the large latent heat can cause severe tissue damage if condensation occurs on the skin.

Conceptual Example: The physics of high-tech clothing.

By taking advantage of the latent heat of fusion, designers can now engineer clothing that can absorb or release heat to help maintain a comfortable and approximately constant temperature close to your body.

As the photograph in Figure shows, the fabric in this type of clothing is coated with microscopic balls of heat-resistant plastic that contain a substance known as a **phase-change material** (PCM).



47 / 56

Conceptual Example: The physics of high-tech clothing.

- When you are enjoying your favorite winter sport, for example, it is easy to become overheated.
- The PCM prevents this by melting, absorbing excess body heat in the process.
- When you are taking a break and cooling down, however, the PCM freezes and releases heat to keep you warm.
- The temperature range over which the PCM can maintain a comfort zone is related to its melting/freezing temperature, which is determined by its chemical composition.

48 / 56

Check Your Understanding 13

Fruit blossoms are permanently damaged at temperatures of about $4\text{ }^{\circ}\text{C}$ (a hard freeze). Orchard owners sometimes spray a film of water over the blossoms to protect them when a hard freeze is expected. Why does this technique offer protection?

Check Your Understanding 14

When ice cubes are used to cool a drink, both their mass and temperature are important in how effective they are. The table lists several possibilities for the mass and temperature of the ice cubes used to cool one particular drink. Rank the possibilities in descending order (best first)

	Mass of ice cubes	Temperature of ice cubes
(a)	m	$-6.0\text{ }^{\circ}\text{C}$
(b)	$\frac{1}{2}m$	$-12\text{ }^{\circ}\text{C}$
(c)	$2m$	$-3.0\text{ }^{\circ}\text{C}$

according to their cooling effectiveness. Note that the latent heat of phase change and the specific heat capacity must be considered.

49 / 56

Problem 57

How much heat must be added to 0.45 kg of aluminum to change it from a solid at $130\text{ }^{\circ}\text{C}$ to a liquid at $660\text{ }^{\circ}\text{C}$ (its melting point)? The latent heat of fusion for aluminum is $4.0 \times 10^5\text{ J/kg}$.

50 / 56

Problem 63

The latent heat of vaporization of H_2O at body temperature ($37.0^\circ C$) is 2.42×10^6 J/kg. To cool the body of a 75 kg jogger, average specific heat capacity is 3500 J/(kg $^\circ C$) by 1.5 $^\circ C$, how many kilograms of water in the form of sweat have to be evaporated?

51 / 56

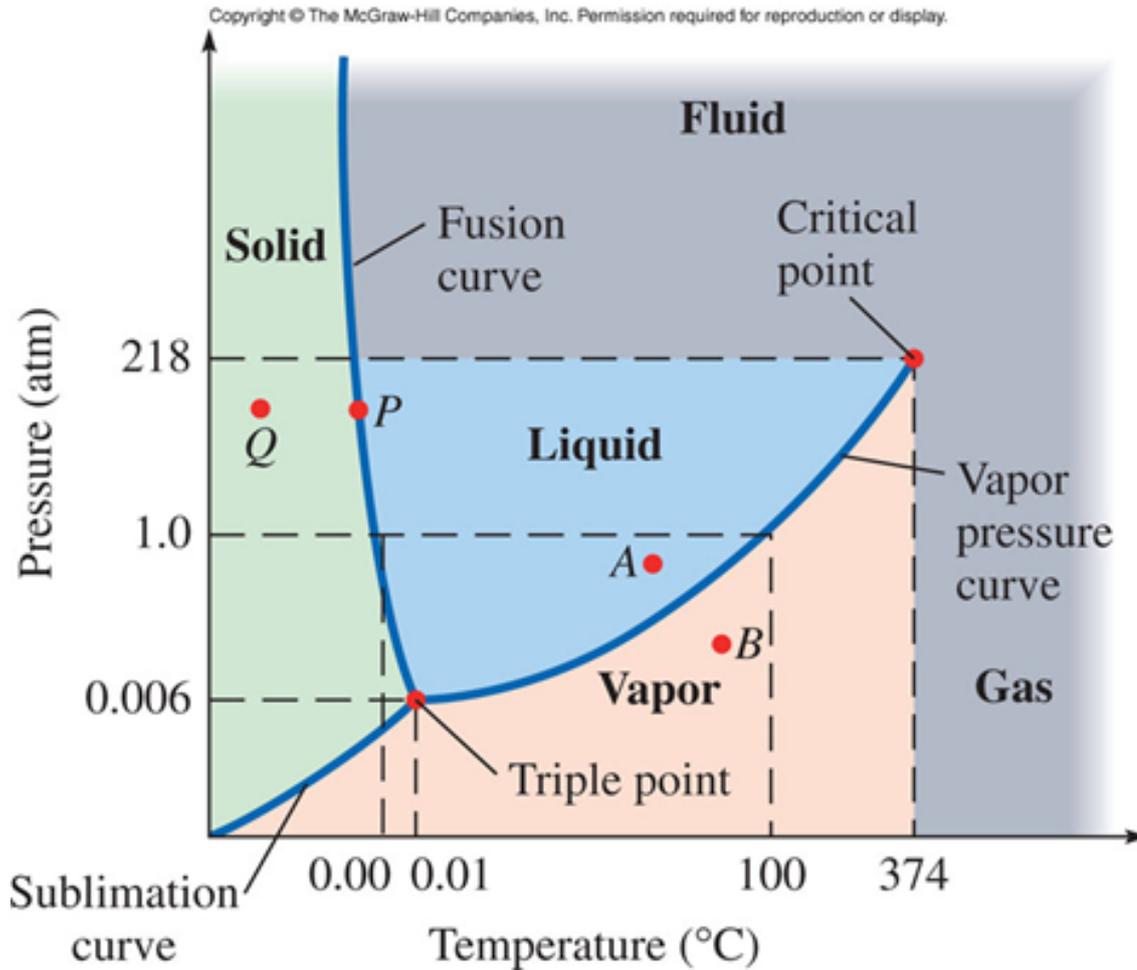
Evaporation

Evaporation is a type of vaporization that occurs on the surface of a liquid as it changes into the gas phase before reaching its boiling point.

- The surrounding gas must not be saturated with the evaporating substance.
- When the molecules of the liquid collide, they transfer energy to each other based on how they collide.
- When a molecule near the surface absorbs enough energy to overcome the vapor pressure, it will "escape" and enter the surrounding air as a gas.
- When evaporation occurs, the energy removed from the vaporized liquid will reduce the temperature of the liquid, resulting in evaporative cooling.

52 / 56

Evaporation



53 / 56

Check Your Understanding 15

A camping stove is used to boil water high on a mountain, where the atmospheric pressure is lower than it is at sea level. Does it necessarily follow that the same stove can boil water at sea level?

Check Your Understanding 15

Medical instruments are sterilized at a high temperature in an autoclave, which is essentially a pressure cooker that heats the instruments in water under a pressure greater than one atmosphere. Why is the water in an autoclave able to reach a very high temperature, while water in an open pot can only be heated to 100 °C?

54 / 56

Check Your Understanding 17

A jar is half filled with boiling water. The lid is then screwed on the jar. After the jar has cooled to room temperature, the lid is difficult to remove. Why? Ignore the thermal expansion and contraction of the jar and the lid

Check Your Understanding 18

A bottle of carbonated soda (sealed and under a pressure greater than one atmosphere) is left outside in subfreezing temperatures, although the soda remains liquid. When the soda is brought inside and opened immediately, it suddenly freezes. Why?

Check Your Understanding 19

When a bowl of water is placed in a closed container and the water vapor is pumped away rapidly enough, why does the remaining liquid turn into ice?

55 / 56

Homework Problems: 1, 2, 11, 17, 19, 31, 47, 58

The End

56 / 56

The Ideal Gas Law and Kinetic Theory (Chapter 14)

- 1 Molecular Mass, the Mole, and Avogadro's Number
- 2 The Ideal Gas Law
- 3 Kinetic Theory of Gases
- 4 Diffusion

1 / 39

Molecular Mass, the Mole, and Avogadro's Number

By international agreement, the reference element is chosen to be the most abundant type of carbon, called carbon-12

The dalton or unified atomic mass unit is a unit of mass widely used in physics and chemistry.

It is defined precisely as 1/12 of the mass of an unbound neutral atom of carbon-12 in its nuclear and electronic ground state and at rest.

$$1u = \frac{1}{12} \frac{0.012 \text{ kg/mole}}{6.022 \times 10^{23} / \text{mole}} = 1.66 \times 10^{-27} \text{ kg}$$

The molecular mass of a molecule is the sum of the atomic masses of its atoms. For instance, hydrogen and oxygen have atomic masses of 1.007 94 u and 15.9994 u, respectively. The molecular mass of a water molecule (H_2O) is:

$$2(1.00794u) + 15.9994u = 18.0153u.$$

The number of atoms per mole is known as Avogadro's number N_A , after the Italian scientist Amedeo Avogadro (1776-1856):

$$N_A = 6.022 \times 10^{23} / \text{mole}$$

2 / 39

Molecular Mass, the Mole, and Avogadro's Number

Periodic Table of the Elements

© 2015 Todd Helmenstine
sciencenotes.org

3 / 39

Molecular Mass, the Mole, and Avogadro's Number

The number of moles n contained in any sample is the number of particles N in the sample divided by the number of particles per mole N_A (Avogadro's number):

$$n = \frac{N}{N_A}$$

The number of moles contained in a sample can also be found from its mass.

$$n = \frac{m_{\text{particle}} N}{m_{\text{particle}} N_A} = \frac{\text{mass of sample}}{\text{mass per mole}}$$

4 / 39

Check Your Understanding 1

Consider one mole of hydrogen (H_2) and one mole of oxygen (O_2). Which, if either, has the greater number of molecules and which, if either, has the greater mass?

Check Your Understanding 2

The molecules of substances A and B are composed of different atoms. However, the two substances have the same mass densities. Consider the possibilities for the molecular masses of the two types of molecules and decide whether 1 m^3 of substance A contains the same number of molecules as 1 m^3 of substance B.

Check Your Understanding 3

A gas mixture contains equal masses of the monatomic gases argon (atomic mass = 39.948 u) and neon (atomic mass = 20.179 u). These two are the only gases present. Of the total number of atoms in the mixture, what percentage is neon?

5 / 39

Problem 2

Manufacturers of headache remedies routinely claim that their own brands are more potent pain relievers than the competing brands. Their way of making the comparison is to compare the number of molecules in the standard dosage. Tylenol uses 325 mg of acetaminophen ($C_8H_9NO_2$) as the standard dose, whereas Advil uses 200 mg of ibuprofen ($C_{13}H_{18}O_2$). Find the number of molecules of pain reliever in the standard doses of (a) Tylenol and (b) Advil.



6 / 39

The Ideal Gas Law

An ideal gas is an idealized model for real gases that have sufficiently low densities.

The condition of low density means that the molecules of the gas are so far apart that they do not interact (except during collisions that are effectively elastic).

The ideal gas law expresses the relationship between the absolute pressure (P), the Kelvin temperature (T), the volume (V), and the number of moles (n) of the gas.

$$PV = nRT$$

Where R is the universal gas constant. $R = 8.31 \text{ J}/(\text{mol}\cdot\text{K})$.

$$PV = nN_A \frac{R}{N_A} T = NkT$$

The constant term R/N_A is referred to as Boltzmann's constant, in honor of the Austrian physicist Ludwig Boltzmann (1844-1906), and is represented by the symbol k:

7 / 39

The Ideal Gas Law

$$k = \frac{R}{N_A} = \frac{8.314 \text{ J}/(\text{mole} \cdot \text{K})}{6.022 \times 10^{23} / \text{mole}} = 1.38 \times 10^{-23} \text{ J/K}$$

From this, you can determine that 1 mole of any gas at atmospheric pressure and at 0 °C is 22.4 L

Gas Laws

When a gas is kept at a constant temperature, its pressure is inversely proportional to its volume (Boyle's law)

$$PV = nRT = \text{constant}$$

When a gas is kept at a constant pressure, its volume is directly proportional to its temperature (Charles and Gay-Lussac's law)

$$P = \frac{nRT}{V} = \text{constant}$$

When the volume of the gas is kept constant, the pressure is directly proportional to the temperature (Gay-Lussac's law)

$$V = nR \frac{T}{P} = \text{constant}$$

8 / 39



The Physics of Oxygen in the Lungs.

In the lungs, a thin respiratory membrane separates tiny sacs of air (absolute pressure = 1.00×10^5 Pa) from the blood in the capillaries. These sacs are called alveoli, and it is from them that oxygen enters the blood. The average radius of the alveoli is 0.125 mm, and the air inside contains 14 % oxygen. Assuming that the air behaves as an ideal gas at body temperature (310 K), find the number of oxygen molecules in one of the sacs.

9 / 39

Check Your Understanding 4

A tightly sealed house has a large ceiling fan that blows air out of the house and into the attic. The owners turn the fan on and forget to open any windows or doors. What happens to the air pressure in the house after the fan has been on for a while, and does it become easier or harder for the fan to do its job?

Check Your Understanding 5

Above the liquid in a can of hair spray is a gas at a relatively high pressure. The label on the can includes the warning “DO NOT STORE AT HIGH TEMPERATURES.” Why is the warning given?

Check Your Understanding 6

What happens to the pressure in a tightly sealed house when the electric furnace turns on and runs for a while?

10 / 39

Check Your Understanding 7

When you climb a mountain, your eardrums “pop” outward as the air pressure decreases. When you come down, they pop inward as the pressure increases. At the sea coast, you swim through a completely submerged passage and emerge into a pocket of air trapped within a cave. As the tide comes in, the water level in the cave rises, and your eardrums pop. Is this popping analogous to what happens as you climb up or climb down a mountain?

Check Your Understanding 8

Atmospheric pressure decreases with increasing altitude. Given this fact, explain why helium-filled weather balloons are underinflated when they are launched from the ground. Assume that the temperature does not change much as the balloon rises.

Check Your Understanding 10

Consider equal masses of three monatomic gases: argon (atomic mass is 39.948 u), krypton (atomic mass = 83.80 u), and xenon (atomic mass = 131.29 u). The pressure and volume of each gas is the same. Which gas has the greatest and which the smallest temperature?

11 / 39

Focus on Concepts 3

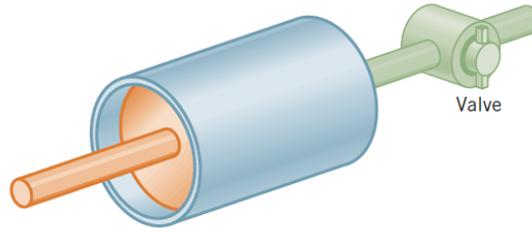
For an ideal gas, each of the following unquestionably leads to an increase in the pressure of the gas, except one. Which one is it?

- A** Increasing the temperature and decreasing the volume, while keeping the number of moles of the gas constant
- B** Increasing the temperature, the volume, and the number of moles of the gas
- C** Increasing the temperature, while keeping the volume and the number of moles of the gas constant
- D** Increasing the number of moles of the gas, while keeping the temperature and the volume constant
- E** Decreasing the volume, while keeping the temperature and the number of moles of the gas constant..

12 / 39

Focus on Concepts 4

The cylinder in the drawing contains 3.00 mol of an ideal gas. By moving the piston, the volume of the gas is reduced to one-fourth its initial value, while the temperature is held constant. How many moles Δn of the gas must be allowed to escape through the valve, so that the pressure of the gas does not change?



13 / 39

Problem 13

An ideal gas at 15.5°C and a pressure of 1.72×10^5 Pa occupies a volume of 2.81 m^3 . (a) How many moles of gas are present? (b) If the volume is raised to 4.16 m^3 and the temperature raised to 28.2°C , what will be the pressure of the gas?

14 / 39

Problem 22

A tank contains 0.85 mol of molecular nitrogen (N_2). Determine the mass (in grams) of nitrogen that must be removed from the tank in order to lower the pressure from 38 to 25 atm. Assume that the volume and temperature of the nitrogen in the tank do not change.

15 / 39

Problem 59

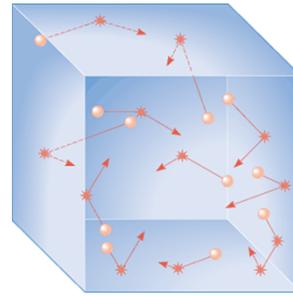
Oxygen for hospital patients is kept in special tanks, where the oxygen has a pressure of 65.0 atmospheres and a temperature of 288 K. The tanks are stored in a separate room, and the oxygen is pumped to the patient's room, where it is administered at a pressure of 1.00 atmosphere and a temperature of 297 K. What volume does 1.00 m^3 of oxygen in the tanks occupy at the conditions in the patient's room?

16 / 39

Kinetic Theory of Gases

The kinetic theory of gases:

- describes a gas as a large number of submicroscopic particles, all of which are in constant, rapid, random motion.
- The randomness arises from the particles' many collisions with each other and with the walls of the container.
- The pressure that a gas exerts is caused by the impact of its molecules on the walls of the container.



It can be shown that the average translational kinetic energy of a molecule of an ideal gas is given by,

$$\overline{KE} = \frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$$

where k is Boltzmann's constant and T is the Kelvin temperature

The root mean square (rms) speed is the square root of the average of the squares of the speeds. Square, average, take the square root

17 / 39

Kinetic Theory of Gases

Solving for v_{rms} we find M is the molar mass and $M = mN_A$

$$\overline{KE} = \frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$$

$$v_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{mN_A}} = \sqrt{\frac{3RT}{M}}$$

If two ideal gases have the same temperature, the relation indicates that the average kinetic energy of each kind of gas particle is the same. In general, however, the rms speeds of the different particles are not the same, because the masses may be different.

18 / 39

The Internal Energy of a Monatomic Ideal Gas I

Internal Energy of an Ideal Gas The internal energy is the total of all the energy associated with the motion of the atoms or molecules in the system. Microscopic forms of energy include those due to the rotation, vibration, translation, and interactions among the molecules of a substance.

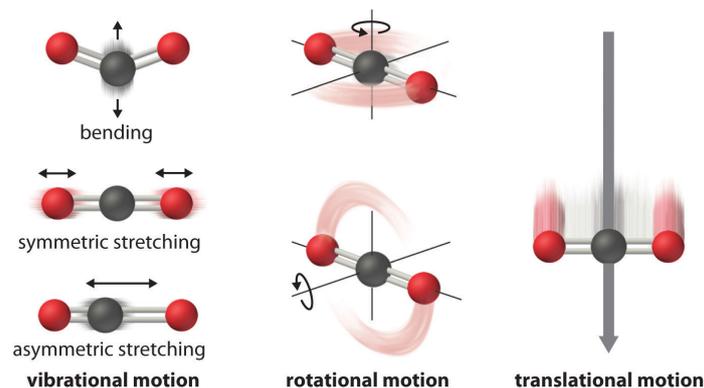
Monatomic Gas – Internal Energy

For a monatomic ideal gas (such as helium, neon, or argon), the only contribution to the energy comes from translational kinetic energy. The average translational kinetic energy of a single atom depends only on the gas temperature and is given by equation:

$$\overline{KE} = \frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$$

19 / 39

The Internal Energy of a Monatomic Ideal Gas II



The internal energy of n moles of an ideal monatomic (one atom per molecule) gas is equal to the average kinetic energy per molecule times the total number of molecules, N :

$$U = \frac{3}{2}NKT = \frac{3}{2}nRT$$

20 / 39

Focus on Concepts 8

The pressure of a monatomic ideal gas is doubled, while the volume is cut in half. By what factor is the internal energy of the gas multiplied?

- A 1/4
- B 1/2
- C 1
- D 2
- E 4

21 / 39

Problem 35

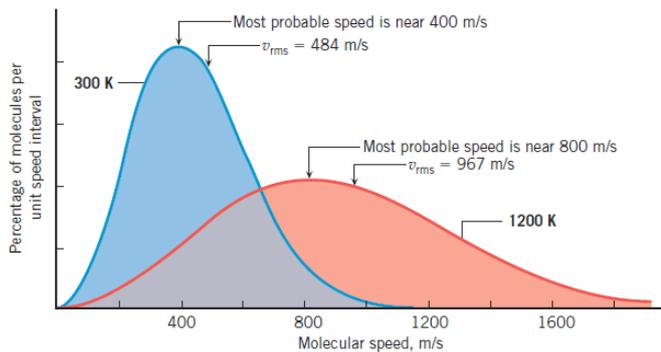
Suppose a tank contains 680 m^3 of neon (Ne) at an absolute pressure of $1.01 \times 10^5 \text{ Pa}$. The temperature is changed from 293.2 to 294.3 K. What is the increase in the internal energy of the neon?

22 / 39

Conceptual Example: Does a Single Particle Have a Temperature? I

Each particle in a gas has kinetic energy. Furthermore, the equation establishes the relationship between the average kinetic energy per particle and the temperature of an ideal gas. *Is it valid, then, to conclude that a single particle has a temperature?* Reasoning and Solution:

We know that a gas contains an enormous number of particles that are traveling with a distribution of speeds, such as those indicated by the graphs in Figure.



23 / 39

Conceptual Example: Does a Single Particle Have a Temperature? II

Therefore, the particles do not all have the same kinetic energy, but possess a distribution of kinetic energies ranging from very nearly zero to extremely large values. If each particle had a temperature that was associated with its kinetic energy, there would be a whole range of different temperatures within the gas. This is not so, for a gas at thermal equilibrium has only one temperature, a temperature that would be registered by a thermometer placed in the gas. Thus, temperature is a property that characterizes the gas as a whole, a fact that is inherent in the relation

$$\overline{KE} = \frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$$

The term v_{rms} is a kind of average particle speed. Therefore

$$\overline{KE} = \frac{1}{2}mv_{rms}^2$$

24 / 39

Conceptual Example: Does a Single Particle Have a Temperature? III

, is the average kinetic energy per particle and is characteristic of the gas as a whole. Since the Kelvin temperature is proportional to

$$\overline{KE} = \frac{1}{2}mv_{rms}^2$$

it is also a characteristic of the gas as a whole and cannot be ascribed to each gas particle individually. Thus, a single gas particle does not have a temperature.

25 / 39

Check Your Understanding 11

The kinetic theory of gases assumes that, for a given collision time, a gas molecule rebounds with the same speed after colliding with the wall of a container. If the speed after the collision were less than the speed before the collision, the duration of the collision remaining the same, would the pressure of the gas be greater than, equal to, or less than the pressure predicted by kinetic theory?

Check Your Understanding 12

If the temperature of an ideal gas were doubled from 50 to 100 °C, would the average translational kinetic energy of the gas particles also double?

Check Your Understanding 13

The pressure of a monatomic ideal gas doubles, while the volume decreases to one-half its initial value. Does the internal energy of the gas increase, decrease, or remain unchanged?

26 / 39

Check Your Understanding 14

The atoms in a container of helium (He) have the same translational rms speed as the atoms in a container of argon (Ar). Treating each gas as an ideal gas, decide which, if either, has the greater temperature.

Check Your Understanding 15

The pressure of a monatomic ideal gas is doubled, while its volume is reduced by a factor of four. What is the ratio of the new rms speed of the atoms to the initial rms speed?

27 / 39

Diffusion I

Diffusion is a physical process where molecules of a material move from an area of high concentration (where there are many molecules) to an area of low concentration (where there are fewer molecules).

- Diffusion usually happens in a solution in gas or in a liquid.
- It describes the constant movement of particles in all liquids and gases.
- These particles move in all directions bumping into each other.
- Diffusion can only work with gases and liquids.

28 / 39

Diffusion II

Here are some examples of diffusion:

- A sugar cube is left in a beaker of water for a while.
- The smell of ammonia spreads from the front of the classroom to the back of the room.
- Fumes of perfume rise from the bottle when the top is removed.
- Food coloring dropped on the beaker spreads out.
- the smell of food spread in the whole house

29 / 39

Diffusion III

Diffusion is fastest in gases and slowest in solids. The rate of diffusion increases on increasing the temperature of the diffusing substance.

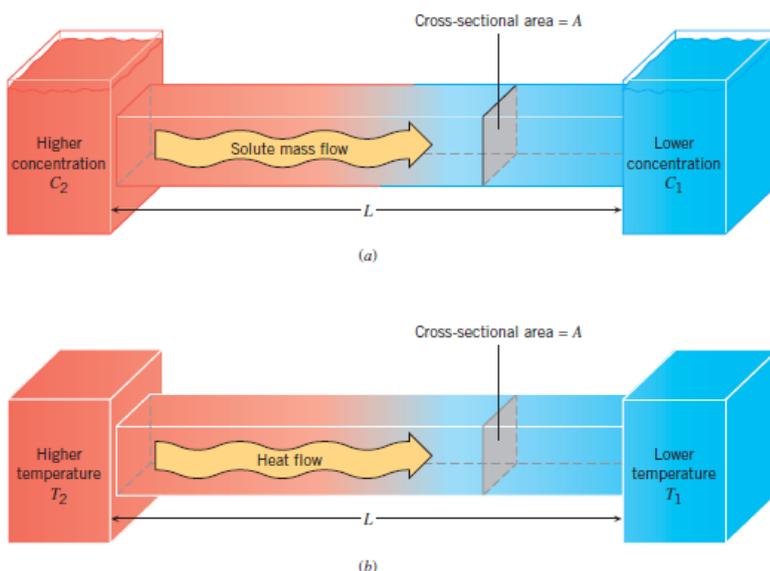


Figure 14.15 (a) Solute diffuses through the channel from the region of higher concentration to the region of lower concentration. (b) Heat is conducted along a bar whose ends are maintained at different temperatures.

The diffusion process can be described in terms of the arrangement in Figure 14.15a. A hollow channel of length L and cross-sectional area A is

30 / 39

Diffusion IV

filled with a fluid. The left end of the channel is connected to a container in which the solute concentration C_2 is relatively high, while the right end is connected to a container in which the solute concentration C_1 is lower. These concentrations are defined as the total mass of the solute molecules divided by the volume of the solution (e.g., 0.1 kg/m^3). Because of the difference in concentration between the ends of the channel, $\Delta C = C_2 - C_1$, there is a net diffusion of the solute from the left end to the right end.

The mass m of solute that diffuses in a time t through a solvent contained in a channel of length L and cross-sectional area A is

$$m = \frac{DA\Delta Ct}{L}$$

where ΔC is the concentration difference between the ends of the channel and D is the diffusion constant. SI Unit for the Diffusion Constant: m^2/s

31 / 39

Conceptual Example: Why Diffusion Is Relatively Slow

The fragrance from an open bottle of perfume takes several seconds or sometimes even minutes to reach the other side of a room by the process of diffusion. Which of the following accounts for the fact that diffusion is relatively slow? (a) The nature of Brownian motion (b) The relatively slow translational rms speeds that characterize gas molecules at room temperature

Reasoning The important characteristic of the paths followed by objects in Brownian motion is their zigzag shapes. We have calculated typical translational rms speeds for gas molecules near room temperature in Example 6, and those results will guide our reasoning here.

Answer (b) is incorrect. In Example 6 we have seen that a gas molecule near room temperature has a translational rms speed of hundreds of meters per second. Such speeds are not slow. It would take a molecule traveling at such a speed just a fraction of a second to cross an ordinary room.

Answer (a) is correct. When a perfume molecule diffuses through air, it makes millions of collisions each second with air molecules. As Figure 14.13 illustrates, the velocity of the molecule changes abruptly because of each collision, but between collisions, it moves in a straight line. Although it does move very fast between collisions, a perfume molecule wanders only slowly away from the bottle because of the zigzag path. It would take a long time indeed to diffuse in this manner across a room. Usually, however, convection currents are present and carry the fragrance to the other side of the room in a matter of seconds or minutes.

32 / 39

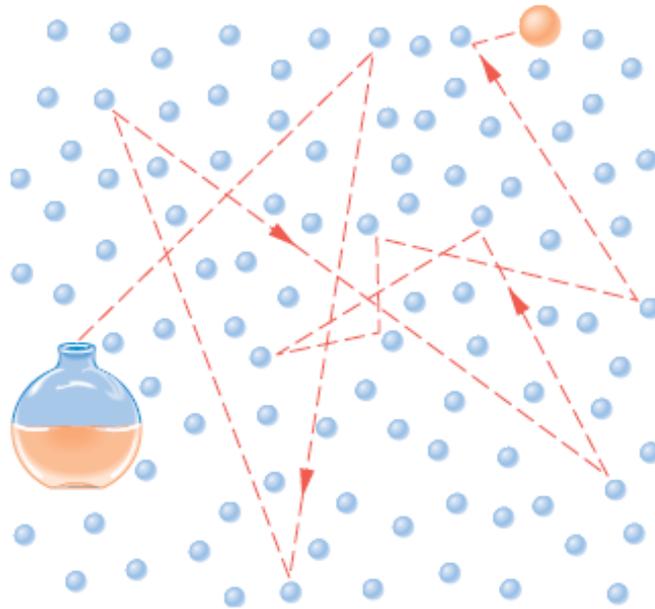


Figure 14.13 A perfume molecule collides with millions of air molecules during its journey, so the path has a zigzag shape. Although the air molecules are shown as stationary, they are also moving.



The physics of drug delivery systems.

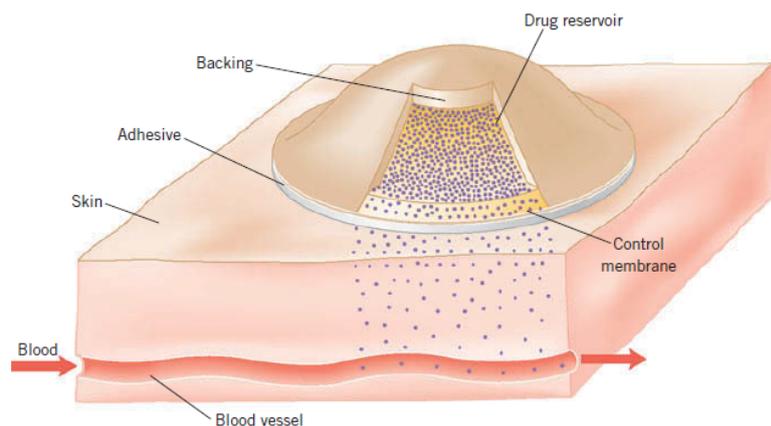


Figure 14.14 Using diffusion, a transdermal patch delivers a drug directly into the skin, where it enters blood vessels. The backing contains the drug within the reservoir, and the control membrane limits the rate of diffusion into the skin.

Diffusion is the basis for drug delivery systems that bypass the need to administer medication orally or via injections. Figure 14.14 shows one such system, the transdermal patch. The word “transdermal” means “across the skin.” Such patches, for example, are used to deliver nicotine in programs designed to help you stop smoking.



The physics of drug delivery systems.

- The patch is attached to the skin using an adhesive, and the backing of the patch contains the drug within a reservoir.
- The concentration of the drug in the reservoir is relatively high, just like the concentration of perfume molecules above the liquid in a bottle. The drug diffuses slowly through a control membrane and directly into the skin, where its concentration is relatively low.
- Diffusion carries it into the blood vessels present in the skin.
- The purpose of the control membrane is to limit the rate of diffusion, which can also be adjusted in the reservoir by dissolving the drug in a neutral material to lower its initial concentration.
- Another diffusion-controlled drug delivery system utilizes capsules that are inserted surgically beneath the skin.

35 / 39

Check Your Understanding 16

In the lungs, oxygen in very small sacs called alveoli diffuses into the blood. The diffusion occurs directly through the walls of the sacs, which have a thickness L . The total effective area A across which diffusion occurs is the sum of the individual areas (each quite small) of the various sac walls. Considering the fact that the mass m of oxygen that enters the blood per second needs to be large and referring to Fick's law of diffusion, what can you deduce about L and about the total number of sacs present in the lungs?

Check Your Understanding 17

The same solute is diffusing through the same solvent in each of three cases. For each case, the table gives the length and cross-sectional area of the diffusion channel. The concentration difference between the ends of the diffusion channel is the same in each case. Rank the diffusion rates (in kg/s) in descending order (largest first).

Case	Length	Cross-Sectional Area
(a)	$\frac{1}{2}L$	A
(b)	L	$\frac{1}{2}A$
(c)	$\frac{1}{3}L$	$2A$

36 / 39

Problem 45

Insects do not have lungs as we do, nor do they breathe through their mouths. Instead, they have a system of tiny tubes, called tracheae, through which oxygen diffuses into their bodies. The tracheae begin at the surface of an insect's body and penetrate into the interior. Suppose that a trachea is 1.9 mm long with a cross sectional area of $2.1 \times 10^{-9} \text{ m}^2$. The concentration of oxygen in the air outside the insect is 0.28 kg/m^3 , and the diffusion constant is $1.1 \times 10^{-5} \text{ m}^2/\text{s}$. If the mass per second of oxygen diffusing through a trachea is $1.7 \times 10^{-12} \text{ kg/s}$, find the oxygen concentration at the interior end of the tube.

37 / 39

Problem 46

A tube has a length of 0.015 m and a cross-sectional area of $7.0 \times 10^{-4} \text{ m}^2$. The tube is filled with a solution of sucrose in water. The diffusion constant of sucrose in water is $5.0 \times 10^{-10} \text{ m}^2/\text{s}$. A difference in concentration of $3.0 \times 10^{-3} \text{ kg/m}^3$ is maintained between the ends of the tube. How much time is required for $8.0 \times 10^{-13} \text{ kg}$ of sucrose to be transported through the tube?

38 / 39

Homework Problems: 5, 11, 15, 33, 48

The End

Thermodynamics (Chapter 15)

- 1 Thermodynamic Systems and Their Surroundings
- 2 Laws of Thermodynamics
- 3 Thermodynamic processes
- 4 Thermodynamic processes - Ideal gas
- 5 Heat Capacity and Molar Heat Capacity
- 6 The Second Law of Thermodynamics: Applications
- 7 The Third Law of Thermodynamics

1 / 45

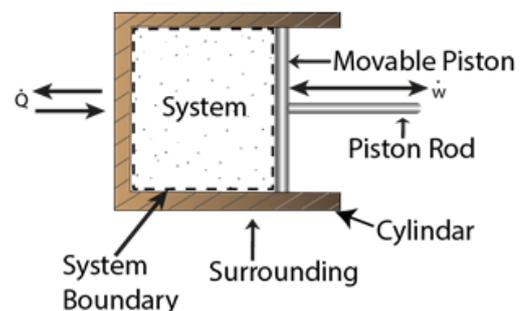
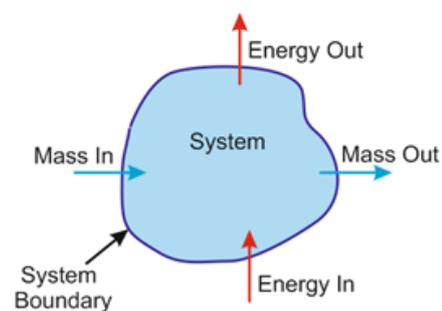
Thermodynamic Systems and Their Surroundings I

Thermodynamics

is the study of the inter-relation between heat, work and internal energy of a system and its interaction with its environment..

System

is the subject of the investigation. A boundary is a closed surface surrounding a system through which energy and mass may enter or leave the system. Everything external to the system is the surroundings.



2 / 45

Thermodynamic Systems and Their Surroundings II

Work, Heat, and Energy

- **Work** is the transfer of energy resulting from a force acting through a distance.
- **Heat** is energy transferred as the result of a temperature difference.
- **Energy** is the capacity to do work.

Neither heat nor work are thermodynamic properties of a system. Heat can be transferred into or out of a system and work can be done on or by a system,

Walls and constraints

A description of a thermodynamic system requires the specification of the walls-boundaries- that separate it from the surroundings and that provide its boundary conditions.

3 / 45

Thermodynamic Systems and Their Surroundings III

Walls used to:

- Isolate the system from the surroundings
- To provide for interaction in specific ways between system and surroundings

Classification of walls and constraints

- Permeable to mass (open system) or non permeable (closed system)
- Movable / rigid
- Permeable to heat (diathermal wall), or non permeable to heat (adiabatic wall)

4 / 45

Thermodynamic Systems and Their Surroundings IV

Isolated systems:

These do not interact in any way with surroundings. The container has to be impermeable to any form of energy or matter. The total energy is a conserved quantity

Closed systems:

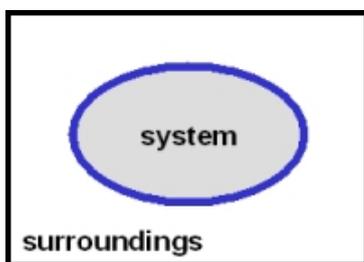
Here one allows only for the exchange of energy with the surroundings, but not for the exchange of matter. Thus the energy is no longer a conserved quantity

Open systems:

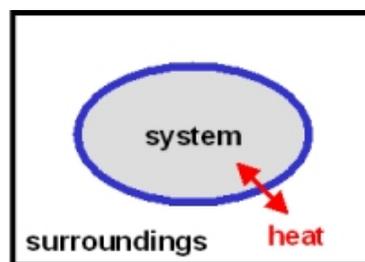
These systems can exchange energy and matter with their surroundings. Hence, neither the energy nor the particle number are conserved

5 / 45

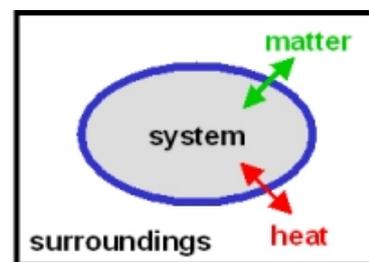
Thermodynamic Systems and Their Surroundings V



- “Isolated” system:
- no exchange of matter
 - no exchange of heat



- “Closed” system:
- no exchange of matter
 - can exchange heat energy



- “Open” system:
- can exchange matter
 - can exchange heat energy

6 / 45

Thermodynamics state variables and transfer variables

A Thermodynamics state variable

describes the state of a system at time t , but it does not reveal how the system was put into that state.

Examples of state variables:

- P = pressure (Pa or N/m^2),
- T = temperature (K),
- V = volume (m^3),
- n = number of moles, and
- U = internal energy (J).

Transfer Variables

- Transfer variables are zero unless a process occurs in which energy is transferred across the boundary of a system
- Transfer variables are not associated with any given state of the system, only with changes in the state

Heat and work are transfer variables

7 / 45

Laws of Thermodynamics

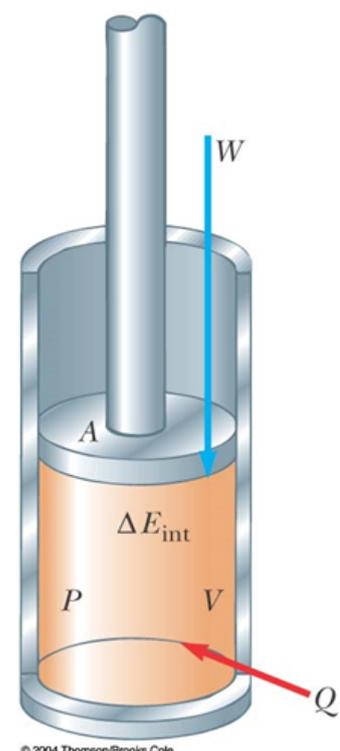
The zeroth law of thermodynamics:

The zeroth law of thermodynamics states that if two thermodynamic systems are each in thermal equilibrium with a third one, then they are in thermal equilibrium with each other.

The first law of thermodynamics

The first law of thermodynamics says the change in internal energy of a system is equal to the heat flow into the system plus the work done on the system (conservation of energy).

$$\Delta U = Q_{\text{added}} + W_{\text{on}}$$



8 / 45

Laws of Thermodynamics

$$\Delta U = Q_{added} + W_{on}$$

$$\Delta U = Q_{added} - W_{by}$$

If energy Q enters the system, its sign is positive.
If energy Q leaves the system, its sign is negative.
If work is done on the system, W_{on} sign is positive.
If work is done by the system, W_{on} sign is negative.

$$W_{on} = -W_{by}$$

9 / 45

Example

Figure 15.3 illustrates a system and its surroundings. In part a, the system gains 1500 J of heat from its surroundings, and 2200 J of work is done by the system on the surroundings. In part b, the system also gains 1500 J of heat, but 2200 J of work is done on the system by the surroundings. In each case, determine the change in the internal energy of the system.

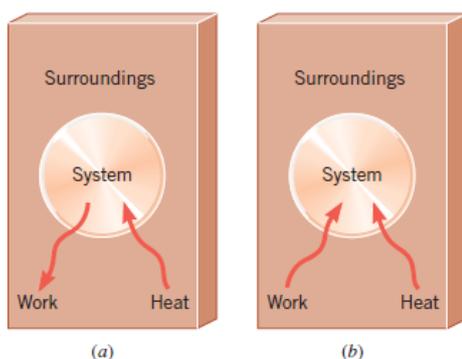


Figure 15.3 (a) The system gains energy in the form of heat but loses energy because work is done by the system. (b) The system gains energy in the form of heat and also gains energy because work is done on the system.

10 / 45

Check Your Understanding 1

A gas is enclosed within a chamber that is fitted with a frictionless piston. The piston is then pushed in, thereby compressing the gas. Which statement below regarding this process is consistent with the first law of thermodynamics?

- A The internal energy of the gas will increase.
- B The internal energy of the gas will decrease.
- C The internal energy of the gas will not change
- D The internal energy of the gas may increase, decrease, or remain the same, depending on the amount of heat that the gas gains or loses.

11 / 45

Problem 2

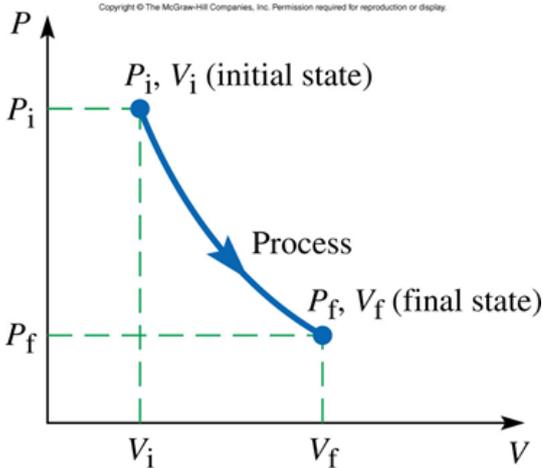
The internal energy of a system changes because the system gains 165 J of heat and performs 312 J of work. In returning to its initial state, the system loses 114 J of heat. During this return process, (a) what work is involved, and (b) is the work done by the system or on the system?

12 / 45

Thermodynamic processes (definitions)

A thermodynamic process is represented by a change in one or more of the thermodynamic state variables describing the system. A change in STATE variables will trigger TRANSFER variables

Each point on the curve represents an equilibrium state of the system.



(b)

13 / 45

Thermodynamic processes (definitions)

Adiabatic process

is one in which no energy is exchanged by heat between a system and its surroundings

$$\Delta U = Q_{added} + W_{on}, \quad Q = 0, \quad \Delta U = W_{on}$$

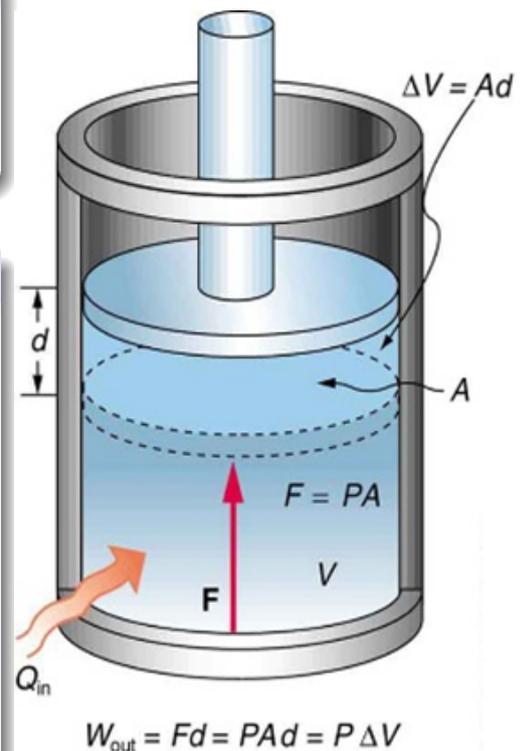
Isobaric process

is one that occurs at constant pressure

$$W_{on} = F_{ext} d \cos \theta = -F_{gas} d \cos 0 = -P \Delta V$$

Work done on the system is positive for compression

Work done on the system is negative for expansion



14 / 45

Thermodynamic processes (definitions)

Isovolumetric (Isochoric) process

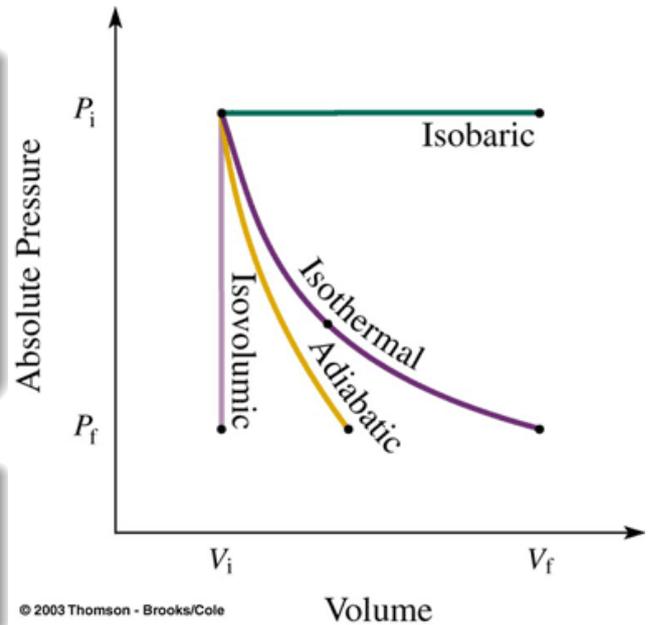
is one that occurs at constant volume. No work is done in such a process

$$\Delta U = Q_{\text{added}} + W_{\text{on}}, \quad W_{\text{on}} = 0,$$

$$\Delta U = Q_{\text{added}}$$

Isothermal process

is one that occurs at constant temperature. There is work done



15 / 45

Problem 8

A system undergoes a two-step process. In the first step, the internal energy of the system increases by 228 J when 166 J of work is done on the system. In the second step, the internal energy of the system increases by 115 J when 177 J of work is done on the system. For the overall process, find the heat. What type of process is the overall process? Explain.

16 / 45

Thermodynamic processes - Ideal gas

Isothermal Expansion or Compression

An isothermal process is one that occurs at a constant temperature

Since there is no change in temperature, any energy that enters the system by heat must leave the system by work

$$\Delta U = Q_{added} + W_{on} = 0, W_{on} = -Q_{added}$$

At right is a PV diagram of an isothermal expansion, the curve is called an isotherm. The curve of the PV diagram indicates $PV = \text{constant}$, which is the equation of a hyperbola. Because it is an ideal gas and the process is quasi-static, $PV = nRT$ and

$$W_{on} = nRT \ln \frac{V_i}{V_f}$$

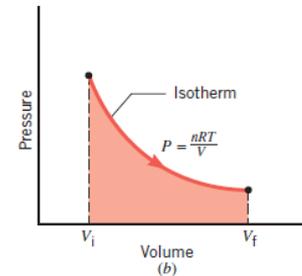


Figure 15.8 (a) The ideal gas in the cylinder is expanding isothermally at temperature T . The force holding the piston in place is reduced slowly, so the expansion occurs quasi-statically. (b) The work done by the gas is given by the colored area.

17 / 45

Thermodynamic processes - Ideal gas

Adiabatic Process

An adiabatic process is one during which no energy enters or leaves the system by heat.

This is achieved by:

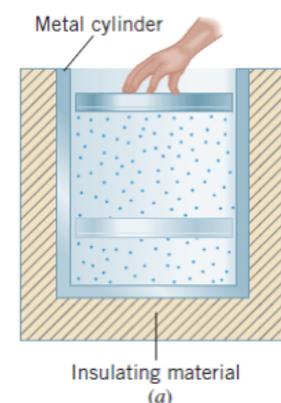
Thermally insulating the walls of the system

OR Having the process proceed so quickly that no heat can be exchanged

$$\Delta U = Q_{added} + W_{on}, Q = 0, \Delta U = W_{on}$$

$$\Delta U = \frac{3}{2} nR \Delta T = W_{on}$$

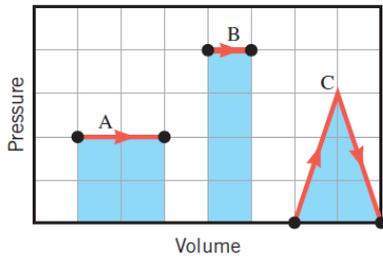
The equation that gives the adiabatic curve between the initial pressure and volume (P_i, V_i) and the final pressure and volume (P_f, V_f) can be derived using integral calculus. The result is $PV^\gamma = \text{constant}$, $\gamma = 5/3$ for monatomic ideal gas



18 / 45

Focus on Concepts 4

The drawing shows the expansion of three ideal gases. Rank the gases according to the work they do, largest to smallest.

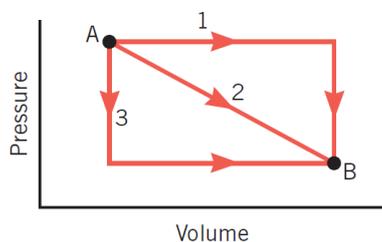


- (A) A, B, C
- (B) A and B (a tie), C
- (C) B and C (a tie), A
- (D) B, C, A
- (E) C, A, B

19 / 45

Focus on Concepts 6

The pressure-volume graph shows three paths in which a gas expands from an initial state A to a final state B. The change in internal energy is the same for each of the paths. Rank the paths according to the heat Q added to the gas, largest to smallest.

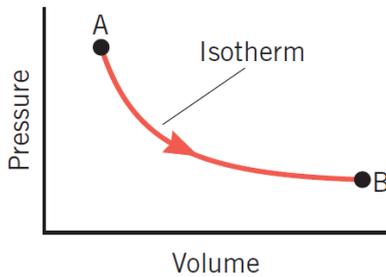


- (A) 1, 2, 3
- (B) 1, 3, 2
- (C) 2, 1, 3
- (D) 3, 1, 2
- (E) 3, 2, 1

20 / 45

Focus on Concepts 8

An ideal monatomic gas expands isothermally from A to B, as the graph shows. What can be said about this process?



- A The gas does no work.
- B No heat enters or leaves the gas.
- C The first law of thermodynamics does not apply to an isothermal process.
- D The ideal gas law is not valid during an isothermal process.
- E There is no change in the internal energy of the gas.

21 / 45

Focus on Concepts 10

A monatomic ideal gas is thermally insulated, so no heat can flow between it and its surroundings. Is it possible for the temperature of the gas to rise?

- A Yes. The temperature can rise if work is done by the gas.
- B No. The only way that the temperature can rise is if heat is added to the gas.
- C Yes. The temperature can rise if work is done on the gas.

22 / 45

Check Your Understanding 2

Is it possible for the temperature of a substance to rise without heat flowing into the substance? (a) Yes, provided that the volume of the substance does not change. (b) Yes, provided that the substance expands and does positive work. (c) Yes, provided that work is done on the substance and it contracts.

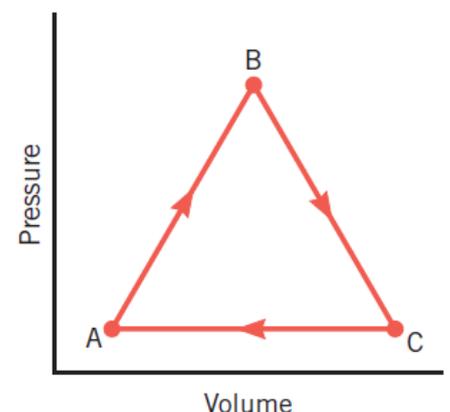
23 / 45

Check Your Understanding 3

The drawing shows a pressure-versus-volume plot for a three-step process: $A \rightarrow B$, $B \rightarrow C$, and $C \rightarrow A$. For each step, the work can be positive, negative, or zero. Which answer in the table correctly describes the work for the three steps?

Work Done by the System

	$A \rightarrow B$	$B \rightarrow C$	$C \rightarrow A$
(a)	Positive	Negative	Negative
(b)	Positive	Positive	Negative
(c)	Negative	Negative	Positive
(d)	Positive	Negative	Zero
(e)	Negative	Positive	Zero

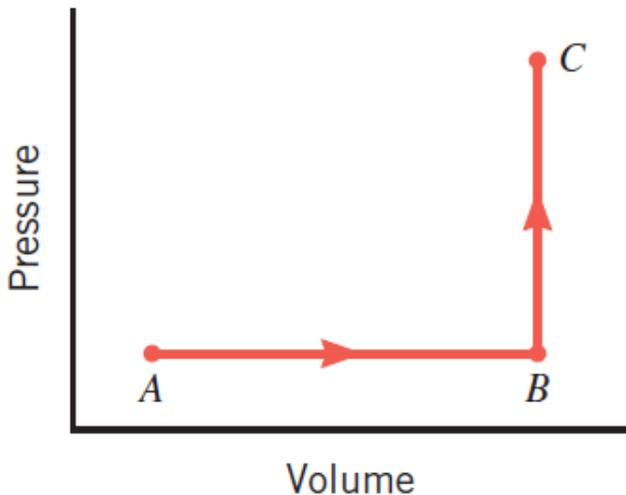


24 / 45

Check Your Understanding 4

The drawing shows a pressure-volume graph in which a gas expands at constant pressure from A to B, and then goes from B to C at constant volume. Complete the table by deciding whether each of the four unspecified quantities is positive (+), negative (-), or zero (0).

	ΔU	Q_{added}	W_{on}	W_{by}
$A \rightarrow B$	+	?	?	?
$B \rightarrow C$?	+	?	?



25 / 45

Check Your Understanding 5

When a solid melts at constant pressure, the volume of the resulting liquid does not differ much from the volume of the solid. According to the first law of thermodynamics, how does the internal energy of the liquid compare to the internal energy of the solid? The internal energy of the liquid is (a) greater than, (b) the same as, (c) less than the internal energy of the solid.

Check Your Understanding 6

One hundred joules of heat is added to a gas, and the gas expands at constant pressure. Is it possible that the internal energy increases by 100 J? (a) Yes (b) No; the increase in the internal energy is less than 100 J, since work is done by the gas. (c) No; the increase in the internal energy is greater than 100 J, since work is done by the gas.

26 / 45

Check Your Understanding 7

A gas is compressed isothermally, and its internal energy increases. Is the gas an ideal gas? (a) No, because if the temperature of an ideal gas remains constant, its internal energy must also remain constant. (b) No, because if the temperature of an ideal gas remains constant, its internal energy must decrease. (c) Yes, because if the temperature of an ideal gas remains constant, its internal energy must increase.

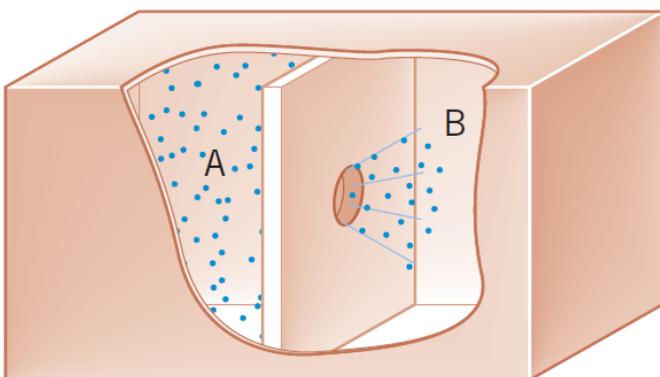
Check Your Understanding 8

A material undergoes an isochoric process that is also adiabatic. Is the internal energy of the material at the end of the process (a) greater than, (b) less than, or (c) the same as it was at the start?

27 / 45

Check Your Understanding 9

The drawing shows an arrangement for an adiabatic free expansion or “throttling” process. The process is adiabatic because the entire arrangement is contained within perfectly insulating walls. The gas in chamber A rushes suddenly into chamber B through a hole in the partition. Chamber B is initially evacuated, so the gas expands there under zero external pressure and the work ($W = P\Delta V$) it does is zero. Assume that the gas is an ideal gas. How does the final temperature of the gas after expansion compare to its initial temperature? The final temperature is (a) greater than, (b) less than, (c) the same as the initial temperature.



28 / 45

Problem 21

Five moles of a monatomic ideal gas expand adiabatically, and its temperature decreases from 370 to 290 K. Determine (a) the work done (including the algebraic sign) by the gas, and (b) the change in its internal energy.

29 / 45

Heat Capacity and Molar Heat Capacity

The heat capacity specifies the heat needed to raise a certain amount of a substance by 1 K. For a gas, the molar heat capacity c_m is the heat required to increase the temperature of 1 mole of gas by 1 K.

Important: The heat capacity depends on whether the heat is added at constant volume or constant pressure.

The molar heat capacity of a substance, which may be denoted by c_m , is the heat capacity C of a sample of the substance, divided by the amount (moles) n of the substance in the sample:

$$c_m = \frac{C}{n} = \frac{Q}{n\Delta T}$$

30 / 45

Heat Capacity and Molar Heat Capacity

The injection of heat energy into a substance, besides raising its temperature, usually causes an increase in its volume and/or its pressure

$$c_m = c_m(T, P, V)$$

Two particular choices are widely used:

If the pressure is kept constant: the sample is allowed to expand, the expansion generates work as the force from the pressure displaces the enclosure. That work must come from the heat energy provided. The value thus obtained is said to be the molar heat capacity at constant pressure (or isobaric), and is often denoted c_p .

If the expansion is prevented (constant volume): no work is generated, and the heat energy that would have gone into it must instead contribute to the internal energy of the object, including raising its temperature by an extra amount. The value obtained this way is said to be the molar heat capacity at constant volume (or isochoric) and denoted c_v

31 / 45

Molar heat capacities of ideal gas

Example

Calculate the molar heat capacity of a monatomic ideal gas at:

- (a) Constant volume
- (b) Constant pressure

32 / 45

Check Your Understanding 10

Suppose that a material contracts when it is heated. Following the same line of reasoning used in the text to reach Equations 15.7 and 15.8, deduce the relationship between the specific heat capacity at constant pressure c_P and the specific heat capacity at constant volume c_V . Which of the following describes the relationship? (a) $c_P = c_V$ (b) c_P is greater than c_V (c) c_P is less than c_V

Check Your Understanding 11

You want to heat a gas so that its temperature will be as high as possible. Should you heat the gas under conditions of (a) constant pressure or (b) constant volume? (c) It does not matter what the conditions are.

33 / 45

Problem 34

Argon is a monatomic gas whose atomic mass is 39.9 u. The temperature of eight grams of argon is raised by 75 K under conditions of constant pressure. Assuming that argon behaves as an ideal gas, how much heat is required?

34 / 45

Problem 37

Heat is added to two identical samples of a monatomic ideal gas. In the first sample the heat is added while the volume of the gas is kept constant, and the heat causes the temperature to rise by 75 K. In the second sample, an identical amount of heat is added while the pressure (but not the volume) of the gas is kept constant. By how much does the temperature of this sample increase?

35 / 45

Problem 40

A monatomic ideal gas expands at constant pressure. (a) What percentage of the heat being supplied to the gas is used to increase the internal energy of the gas? (b) What percentage is used for doing the work of expansion?

36 / 45

The Second Law of Thermodynamics: The Heat Flow Statement

Heat flows spontaneously from a substance at a higher temperature to a substance at a lower

Heat Engines A heat engine is any device that uses heat to perform work. It has three essential features:

- 1 Heat is supplied to the engine at a relatively high input temperature from a place called the hot reservoir.
- 2 Part of the input heat is used to perform work by the working substance of the engine, which is the material within the engine that actually does the work (e.g., the gasoline-air mixture in an automobile engine).
- 3 The remainder of the input heat is rejected to a place called the cold reservoir, which has a temperature lower than the input temperature.

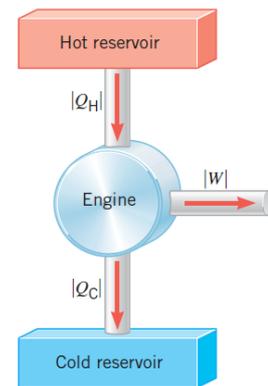


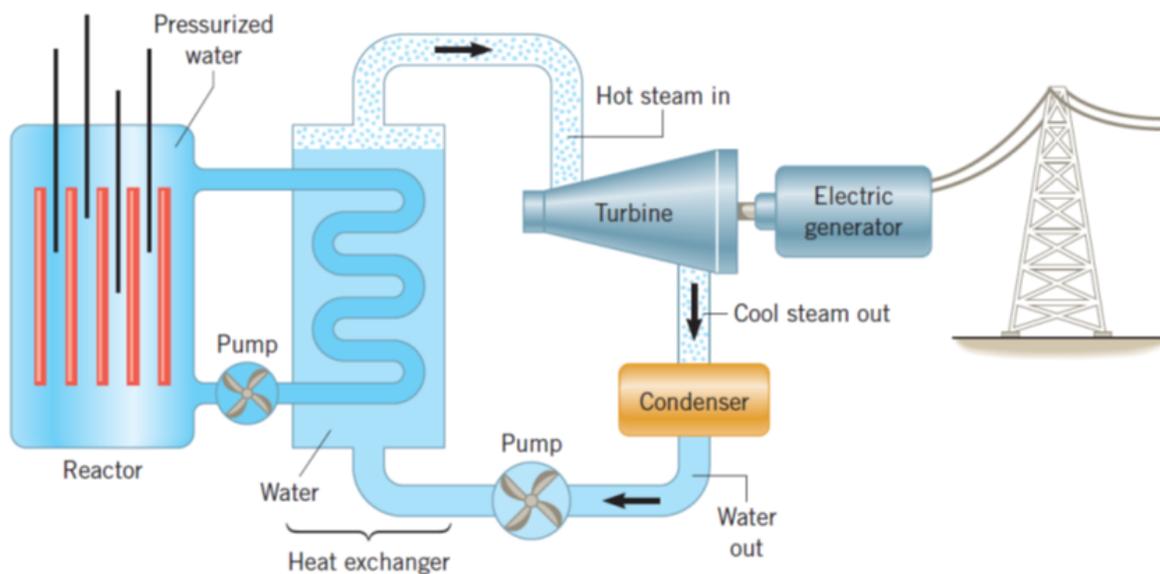
Figure 15.10 This schematic representation of a heat engine shows the input heat (magnitude = $|Q_H|$) that originates from the hot reservoir, the work (magnitude = $|W|$) that the engine does, and the heat (magnitude = $|Q_C|$) that the engine rejects to the cold reservoir.

Efficiency of heat engine:

$$e = \frac{\text{what you want}}{\text{what you give}} = \frac{W}{Q_H}$$

37 / 45

Power Station



The Second Law of Thermodynamics: Clausius Form

It is impossible to construct a cyclical machine whose sole effect is to transfer energy continuously by heat from one object to another object at a higher temperature without the input of energy by work

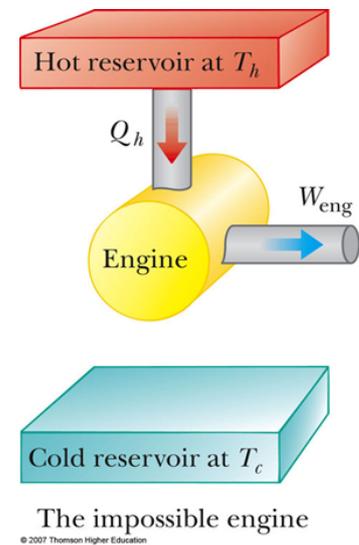
Or - energy does not transfer spontaneously by heat from a cold object to a hot object

Perfect Heat Engine

No energy is expelled to the cold reservoir

It takes in some amount of energy and does an equal amount of work

$e = 100\%$ It is impossible to construct such an engine



39 / 45

Refrigerators, Air Conditioners, and Heat Pumps

The natural tendency of heat is to flow from hot to cold, as indicated by the second law of thermodynamics. However, if work is used, heat can be made to flow from cold to hot, against its natural tendency. Refrigerators, air conditioners, and heat pumps are, in fact, devices that do just that.

The coefficient of performance is:

$$COP = \frac{\text{what you want}}{\text{what you give}}$$

The COP of a refrigerator is $COP = \frac{Q_C}{W}$

The COP of a heat pump (heating) is $COP = \frac{Q_H}{W}$

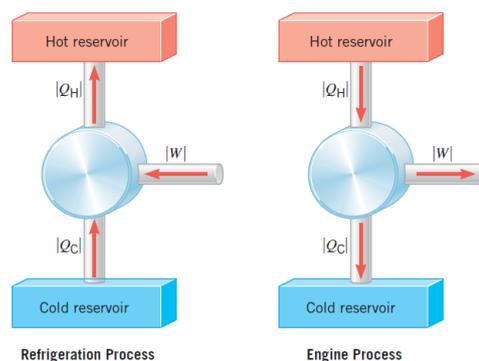


Figure 15.12 In the refrigeration process on the left, work (magnitude = $|W|$) is used to remove heat (magnitude = $|Q_c|$) from the cold reservoir and deposit heat (magnitude = $|Q_h|$) into the hot reservoir. Compare this with the engine process on the right.

40 / 45

Entropy and the Second Law I

Entropy, the measure of a system's thermal energy per unit temperature that is unavailable for doing useful work.

Because work is obtained from ordered molecular motion, the amount of entropy is also a measure of the molecular disorder, or randomness, of a system.

The concept of entropy provides deep insight into the direction of spontaneous change for many everyday phenomena. Its introduction by the German physicist Rudolf Clausius in 1850 is a highlight of 19th-century physics.

By the Clausius definition, if an amount of heat Q flows into a large heat reservoir at temperature T above absolute zero, then the entropy increase is $\Delta S = Q/T$. Assume that there are two heat reservoirs R_H and R_C at temperatures T_H and T_C (such as the stove and the block of

41 / 45

Entropy and the Second Law II

ice). If an amount of heat Q flows from R_H to R_C , then the net entropy change for the two reservoirs is

$$\Delta S = Q\left(\frac{1}{T_C} - \frac{1}{T_H}\right)$$

which is positive provided that $T_H > T_C$. Thus, the observation that heat never flows spontaneously from cold to hot is equivalent to requiring the net entropy change to be positive for a spontaneous flow of heat.

If $T_H = T_C$, then the reservoirs are in equilibrium, no heat flows, and $\Delta S = 0$.

42 / 45

The Third Law of Thermodynamics

It is not possible to lower the temperature of any system to absolute zero $T = 0K$ in a finite number of steps.

The third law of thermodynamic states that as the temperature of a system approaches absolute zero, its entropy becomes constant, or the change in entropy is zero. The third law of thermodynamics predicts the properties of a system and the behavior of entropy in a unique environment known as absolute temperature

43 / 45

Check Your Understanding 21

Two equal amounts of water are mixed together in an insulated container, and no work is done in the process. The initial temperatures of the water are different, but the mixture reaches a uniform temperature. Do the internal energy and entropy of the water increase, decrease, or remain constant as a result of the mixing process?

Check Your Understanding 23

In each of the following cases, which has the greater entropy, a handful of popcorn kernels or the popcorn that results from them; a salad before or after it has been tossed; and a messy apartment or a neat apartment?

44 / 45

Homework Problems: 4, 5, 10, 22, 23, 34, 39

The End

Waves and Sound (Chapter 16)

- 1 The Nature of Waves
- 2 The Speed of a Wave on a String
- 3 The Nature of Sound
- 4 The Speed of Sound
- 5 Hearing sound
- 6 The frequency spectrum of sound waves
- 7 Sound intensity
- 8 Sound Intensity Level: Decibels
- 9 The Doppler Effect
- 10 Supersonic speeds, shock waves
- 11 Applications of Sound in Medicine
 - The physics of ultrasonic imaging.
 - The physics of the cavitron ultrasonic surgical aspirator.
 - Sound waves used for deep brain surgery
 - The physics of the Doppler flow meter.
 - Echocardiogram
 - Kidney Stone Treatment: Shock Wave Lithotripsy.

1 / 64

The Nature of Waves

Types of Waves

Mechanical waves: Some physical medium is being disturbed. The wave is the propagation of a disturbance through a medium

Electromagnetic waves: No medium required. Examples are light, radio waves, x-rays

- In wave motion, energy is transferred over a distance
- Matter is not transferred over a distance
- All waves carry energy, the amount of energy and the mechanism responsible for the transport of the energy differ

Mechanical Wave Requirements

- Some source of disturbance
- A medium that can be disturbed
- Some physical mechanism through which elements of the medium can influence each other

2 / 64

Waves and Sound

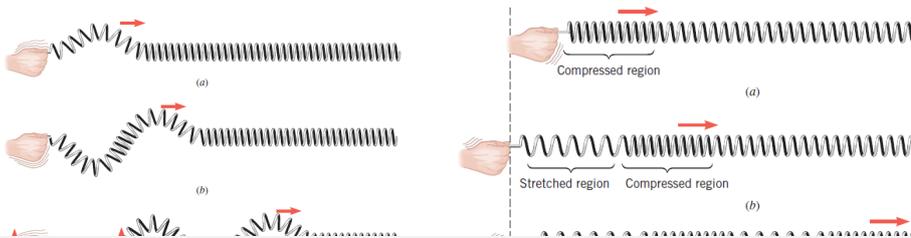
Wave is a disturbance which travels through a medium.

In wave motion energy and momentum are transported from one point to another without the transport of matter

Wave forms

Transverse waves: The disturbance is perpendicular to the direction of propagation of the wave.

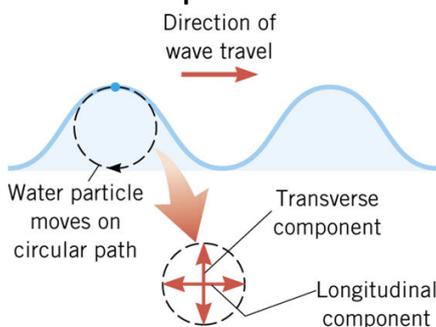
Longitudinal waves: The disturbance is along the direction of propagation



3 / 64

Water Waves

Water waves are an example of waves that involve a combination of both longitudinal and transverse motions. As a wave travels through the water, the particles travel in clockwise circles. The radius of the circles decreases as the depth into the water increases.

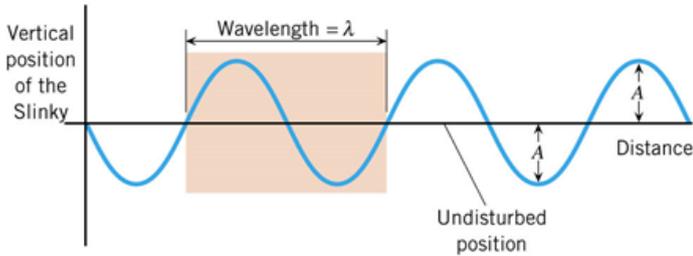


4 / 64

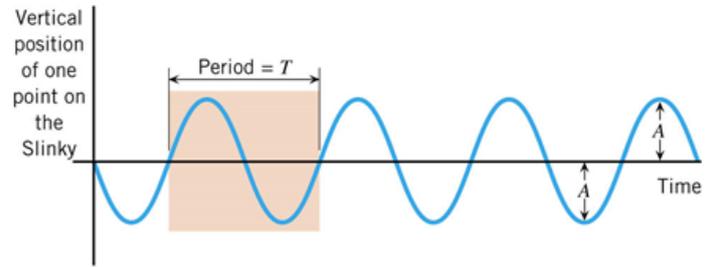
Periodic Waves

The transverse and longitudinal waves are periodic waves and can be described by a sinusoidal function

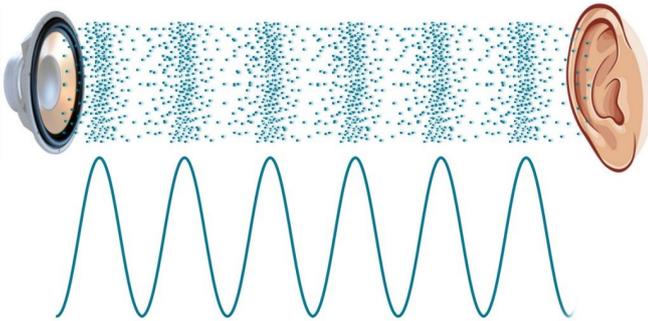
$$\text{speed of wave: } v = \frac{\lambda}{T} = \lambda f$$



(a) At a particular time



(b) At a particular location



5 / 64

Check Your Understanding 1

Considering the nature of a water wave (see Figure 16.4), which of the following statements correctly describes how a fishing float moves on the surface of a lake when a wave passes beneath it? (c)

- A It bobs up and down vertically.
- B It moves back and forth horizontally.
- C It moves in a vertical plane, exhibiting both motions described in (a) and (b) simultaneously.

6 / 64

Check Your Understanding 3

A sound wave (a periodic longitudinal wave) from a loudspeaker travels from air into water. The frequency of the wave does not change, because the loudspeaker producing the sound determines the frequency. The speed of sound in air is 343 m/s, whereas the speed in fresh water is 1482 m/s. When the sound wave enters the water, does its wavelength increase, decrease, or remain the same?

7 / 64

Problem 6

A person fishing from a pier observes that four wave crests pass by in 7.0 s and estimates the distance between two successive crests to be 4.0 m. The timing starts with the first crest and ends with the fourth. What is the speed of the wave?

8 / 64

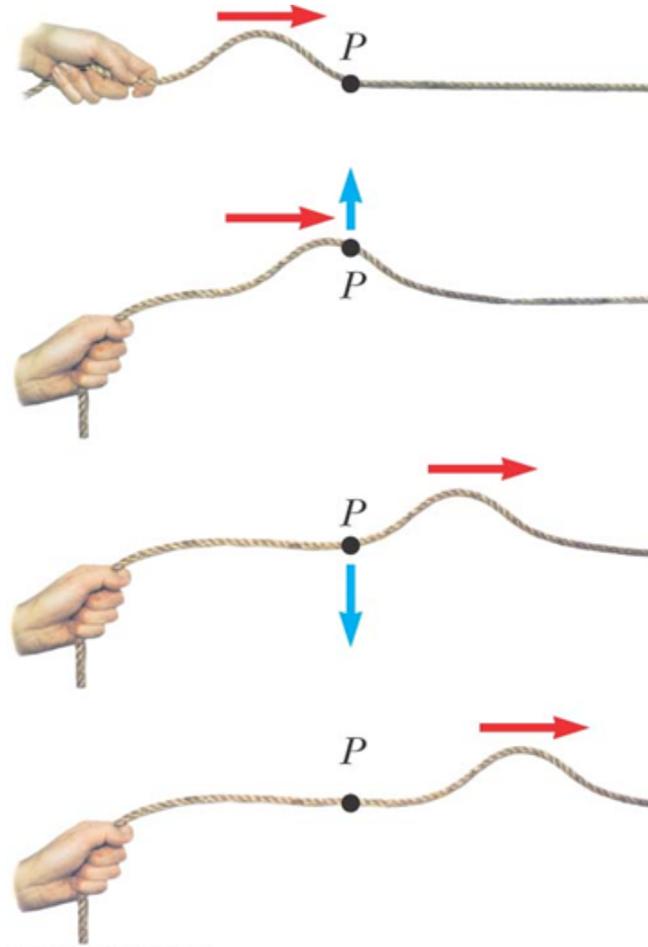
The speed of a wave on a string

A general property of waves is that their speed relative to the medium depends on the properties of the medium but is independent of the motion of the source of the waves
The speed of a small amplitude wave on a string:

$$v = \sqrt{\frac{F}{m/L}}$$

F : is tension, m/L : is the linear density

The speed of a wave on a stretched string is set by properties of the string



© 2004 Thomson/Brooks Cole

Vertical |

9 / 64

Problem 12

The mass of a string is 5.0×10^{-3} kg, and it is stretched so that the tension in it is 180 N. A transverse wave traveling on this string has a frequency of 260 Hz and a wavelength of 0.60 m. What is the length of the string?

Check Your Understanding 4

One end of each of two identical strings is attached to a wall. Each string is being pulled equally tight by someone at the other end. A transverse pulse is sent traveling along string A. A bit later an identical pulse is sent traveling along string B. What, if anything, can be done to make the pulse on string B catch up with and pass the pulse on string A?

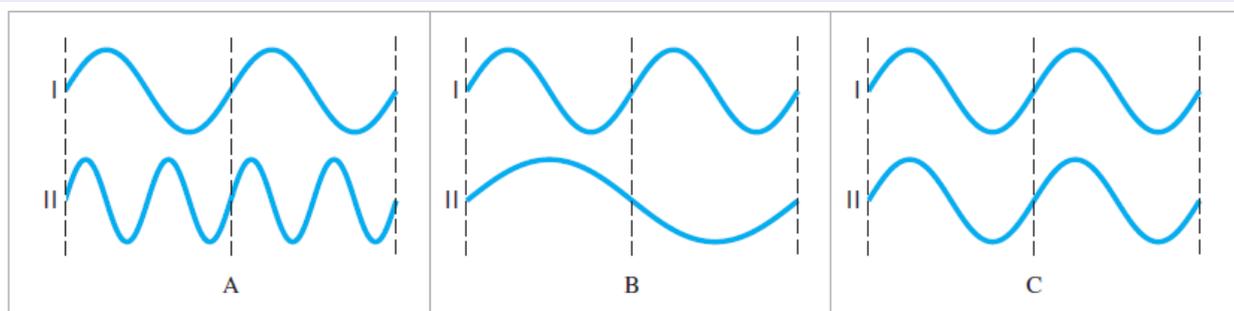
Check Your Understanding 6

A wire is strung tightly between two immovable posts. Review Section 12.4 and decide whether the speed of a transverse wave on this wire would increase, decrease, or remain the same when the temperature increases. Ignore any change in the mass per unit length of the wire.

11 / 64

Check Your Understanding 9

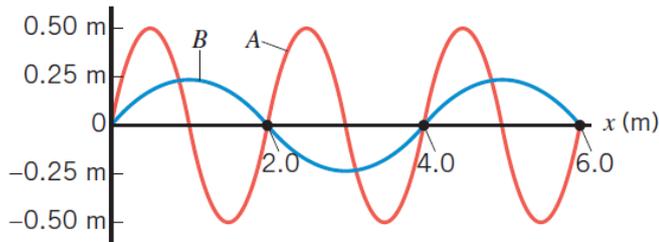
String I and string II have the same length. However, the mass of string I is twice the mass of string II, and the tension in string I is eight times the tension in string II. A wave of the same amplitude and frequency travels on each of these strings. Which of the drawings correctly shows the waves: (a) A (b) B (c) C?



12 / 64

Problem 19

The drawing shows a graph of two waves traveling to the right at the same speed. (a) Using the data in the drawing, determine the wavelength of each wave. (b) The speed of the waves is 12 m/s; calculate the frequency of each one. (c) What is the maximum speed for a particle attached to each wave?



13 / 64

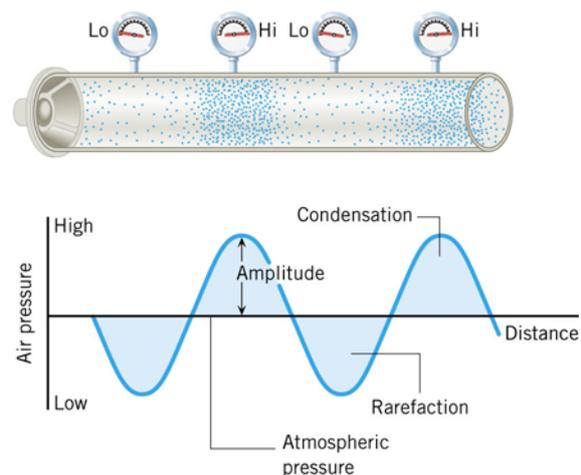
The nature of sound

- Sound is one kind of longitudinal wave, in which the particles oscillate to and fro (back and forth) in the same direction of wave propagation.
- Sound waves cannot be transmitted through vacuum. The transmission of sound requires at least a medium, which can be solid, liquid, or gas.
- Sound wave can be created by a vibrating object such as a fork, guitar string, or human vocal cords
- As the waves travel, the particles in the medium vibrate to changes in density and pressure along the direction of motion.
- The compression causes the air pressure to increase and the region of increased pressure called condensation, the region of low pressure known as rarefaction

14 / 64

The Pressure Amplitude of a Sound Wave

- The sound wave can be described by a sine wave.
- The wave is identified by amplitude (A) (or loudness, size of pressure differences) usually measured in decibels (dB), wavelength, frequency (or pitch) f usually measured in cycles per second, or Hertz (Hz)



The Speed of Sound

Sound travels through gases, liquids, and solids at considerably different speeds, as Table 16.1 reveals. Near room temperature, the speed of sound in air is 343 m/s and is markedly greater in liquids and solids. For example, sound travels more than four times faster in water and more than seventeen times faster in steel than it does in air. In general, sound travels slowest in gases, faster in liquids, and fastest in solids.

Gases: $v = \sqrt{\frac{\gamma kT}{m}}$, $\gamma = \frac{c_p}{c_v}$, m is the mass of the molecule converted into kg.

Liquids: $v = \sqrt{\frac{B}{\rho}}$, B is the Bulk modulus, ρ is density

Solids: $v = \sqrt{\frac{Y}{\rho}}$, Y is the Young modulus, ρ is density

17 / 64

Table 16.1 Speed of Sound in Gases, Liquids, and Solids

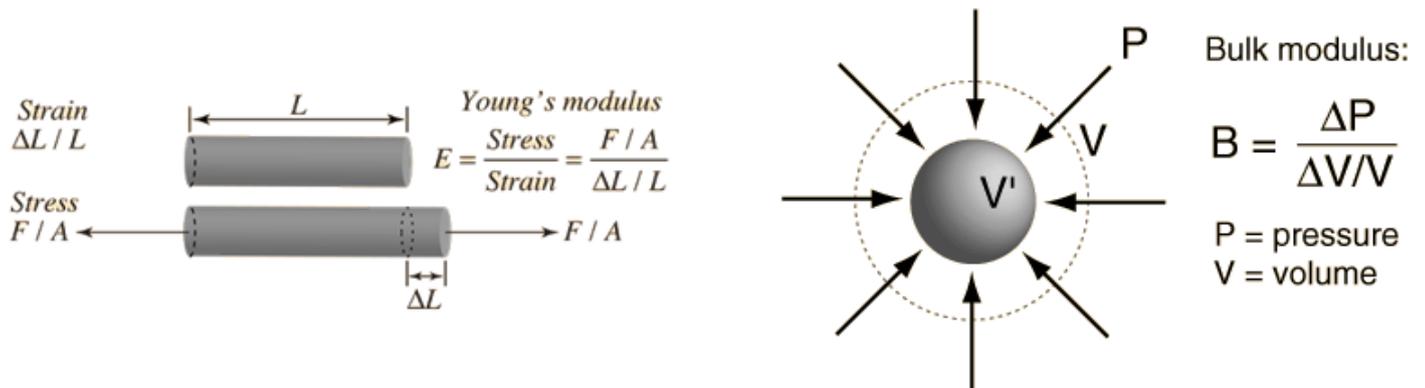
Substance	Speed (m/s)
Gases	
Air (0 °C)	331
Air (20 °C)	343
Carbon dioxide (0 °C)	259
Oxygen (0 °C)	316
Helium (0 °C)	965
Liquids	
Chloroform (20 °C)	1004
Ethyl alcohol (20 °C)	1162
Mercury (20 °C)	1450
Fresh water (20 °C)	1482
Seawater (20 °C)	1522
Solids	
Copper	5010
Glass (Pyrex)	5640
Lead	1960
Steel	5960

18 / 64

The Speed of Sound

The bulk modulus of a substance is a measure of how resistant to compression that substance is. It is defined as the ratio of the infinitesimal pressure increase to the resulting relative decrease of the volume.

Young's modulus is a mechanical property that measures the stiffness of a solid material. It defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material in the linear elasticity regime of a uniaxial deformation.

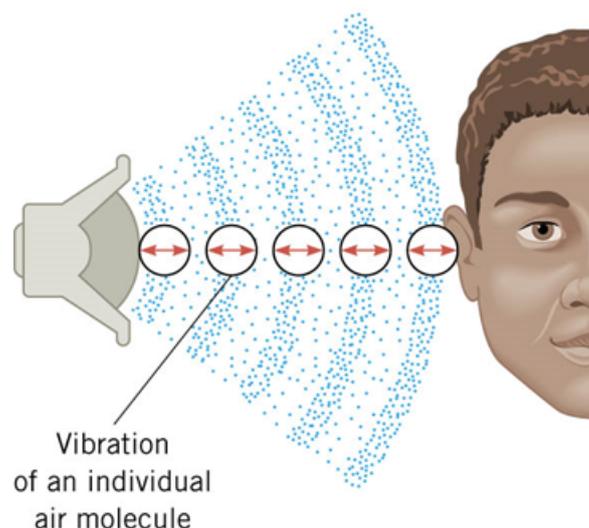


19 / 64

Hearing sound

When a pressure wave reaches the ear, a series of high and low pressure regions impinge upon the eardrum.

- The arrival of a compression “Condensation” or high pressure region pushes the eardrum inward; the arrival of a low pressure regions “rarefaction” serves to pull the eardrum outward.
- The continuous arrival of high and low pressure regions sets the eardrum into vibrational motion

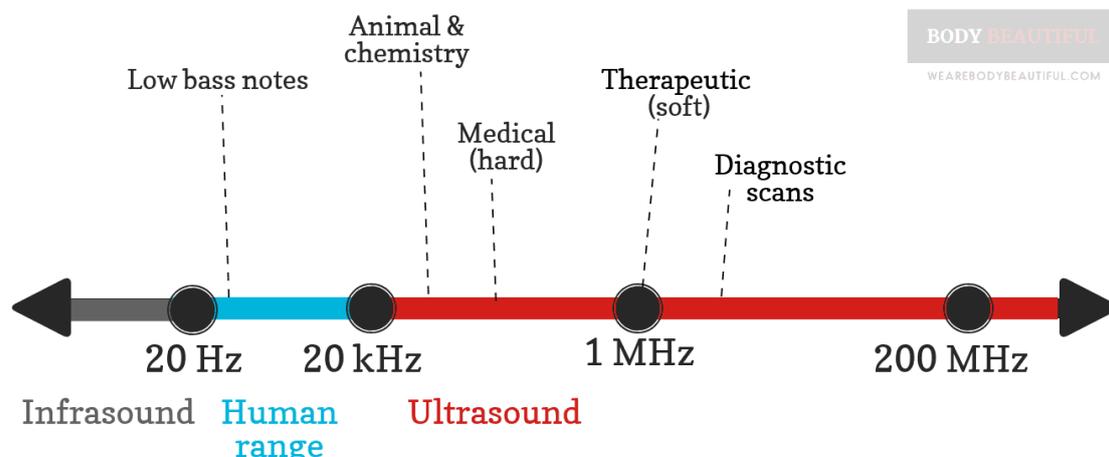


20 / 64

The frequency spectrum of sound waves

Sound waves are divided into three categories that cover different frequency ranges:

- Audible waves: within the range of sensitivity of human ear (20 Hz – 20 kHz)
- Infrasonic waves: having frequencies below 20 Hz (can be heard by elephants)
- Ultrasonic waves: waves having frequencies above 20 kHz (can be heard by dogs)



21 / 64

Check Your Understanding 11

Do you expect an echo to return to you more quickly on a hot day or a cold day, other things being equal?

Check Your Understanding 12

Carbon monoxide (CO), hydrogen (H_2), and nitrogen (N_2) may be treated as ideal gases. Each has the same temperature and nearly the same value for the ratio of the specific heat capacities at constant pressure and constant volume. In which two of the three gases is the speed of sound approximately the same?

Check Your Understanding 13

Jell-O starts out as a liquid and then sets to a gel. As the Jell-O sets and becomes more solid, does the speed of sound in this material increase, decrease, or remain the same?

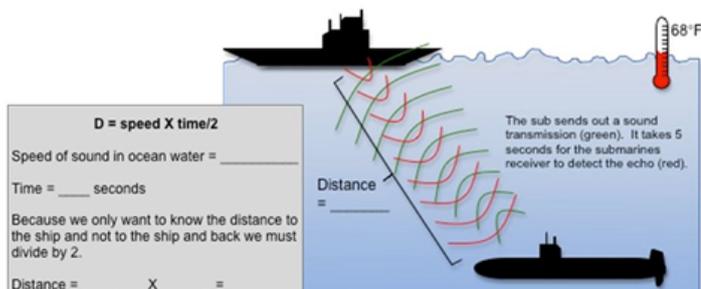
22 / 64

The physics of sonar.

Sonar (sound navigation ranging) is a technique for determining water depth and locating underwater objects, such as reefs, submarines, and schools of fish. The core of a sonar unit consists of an ultrasonic transmitter and receiver mounted on the bottom of a ship. The transmitter emits a short pulse of ultrasonic sound, and at a later time the reflected pulse returns and is detected by the receiver. The distance to the object is determined from the electronically measured round-trip time of the pulse and a knowledge of the speed of sound in water; the distance registers automatically on an appropriate meter.



Basic Sonar Distance Calculation



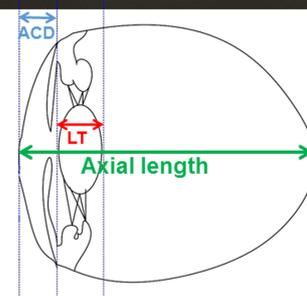
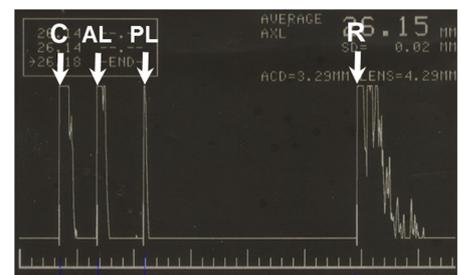
23 / 64



The physics of cataract surgery: The Axial Length.

Accurate distance measurements using ultrasonic sound

- A routine preoperative procedure in cataract surgery uses an ultrasonic probe called an A-scan to measure the length of the eyeball in front of the lens, the thickness of the lens, and the length of the eyeball between the lens and the retina .
- The measurement is similar to that discussed in Sonar example and relies on the fact that the speed of sound in the material in front of and behind the lens of the eye is 1532 m/s, whereas that within the lens is 1641 m/s.
- In cataract surgery, the cataractous lens is removed and often replaced with an implanted artificial lens. Data provided by the A-scan facilitate the design of the lens implant (its size and the optical correction that it introduces)



24 / 64



The physics of cataract surgery: The Axial Length.



25 / 64

Problem 31

For research purposes a sonic buoy is tethered to the ocean floor and emits an infrasonic pulse of sound (speed 1522 m/s). The period of this sound is 71 ms . Determine the wavelength of the sound.

26 / 64

Problem 35

The speed of a sound in a container of hydrogen at 201 K is 1220 m/s. What would be the speed of sound if the temperature were raised to 405 K? Assume that hydrogen behaves like an ideal gas.

27 / 64

Problem 41

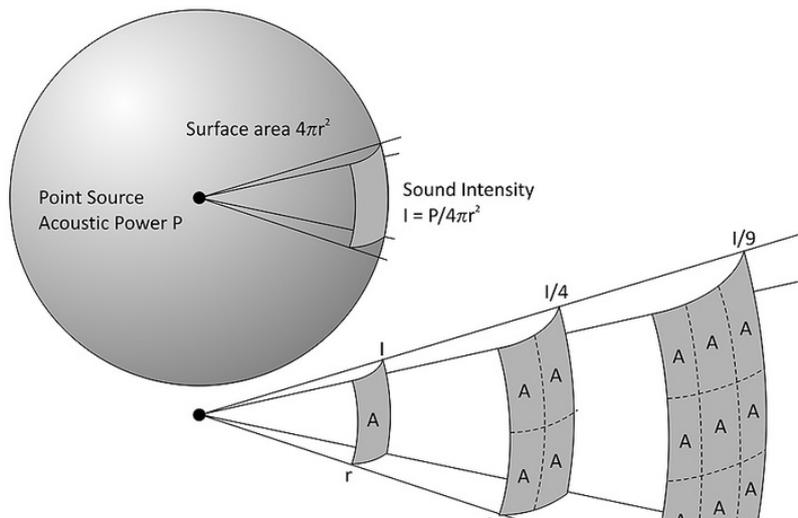
An explosion occurs at the end of a pier. The sound reaches the other end of the pier by traveling through three media: air, fresh water, and a slender metal handrail. The speeds of sound in air, water, and the handrail are 343, 1482, and 5040 m/s, respectively. The sound travels a distance of 125 m in each medium. (a) Through which medium does the sound arrive first, second, and third? (b) After the first sound arrives, how much later do the second and third sounds arrive?

28 / 64

Sound intensity

Sound intensity, also known as acoustic intensity, is defined as the power carried by sound waves per unit area in a direction perpendicular to that area. The SI unit of intensity, which includes sound intensity, is the watt per square meter (W/m^2).

$$Intensity = I = \frac{Power}{Area} = \frac{P}{4\pi r^2}$$



29 / 64

Check Your Understanding 11

Some animals rely on an acute sense of hearing for survival, and the visible parts of the ears on such animals are often relatively large. How does this anatomical feature help to increase the sensitivity of the animal's hearing for low-intensity sounds?

Check Your Understanding 12

A source is emitting sound uniformly in all directions. There are no reflections anywhere. A flat surface faces the source. Is the sound intensity the same at all points on the surface?

30 / 64

Sound Intensity Level: Decibels I

We use a logarithmic scale to describe the intensity level β of sound. Because the ear is sensitive over a broad range of intensities (10^{-12} W/m^2 - 1 W/m^2), a logarithmic scale is usually used

Sound intensity (in W/m^2) is the SI unit, the sound intensity level in decibels (dB) is more relevant for how humans perceive sounds. The way our ears perceive sound can be more accurately described by the logarithm of the intensity of a sound rather than the intensity of a sound directly. The sound intensity level β is defined to be

$$\beta = 10 \log \frac{I}{I_0}$$

where I is sound intensity in watts per meter squared, and $I_0 = 1 \times 10^{-12} \text{ W/m}^2$ is a reference intensity. I_0 is chosen as the reference point because it is the lowest intensity of sound a person with normal hearing can

31 / 64

Sound Intensity Level: Decibels II

perceive. The decibel level of a sound having an intensity of $1 \times 10^{-12} \text{ W/m}^2$ is $\beta = 0 \text{ dB}$, .

That is, the threshold of human hearing is 0 decibels.

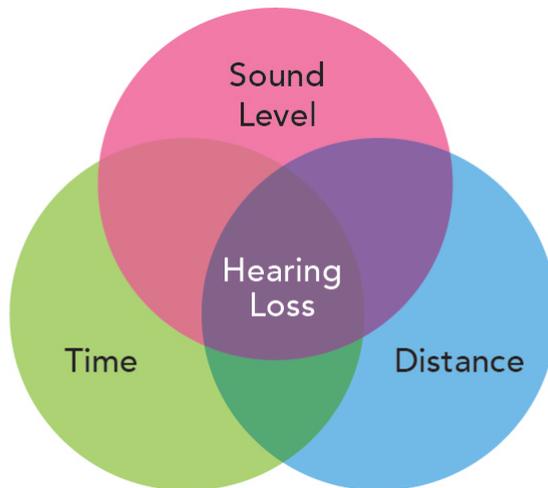
Suppose you are sitting in front of a stereo system that is producing an intensity level of 90 dB. If the volume control on the amplifier is turned up slightly to produce a 91-dB level, you would just barely notice the change in loudness.

Hearing tests have revealed that a one-decibel (1-dB) change in the intensity level corresponds to approximately the smallest change in loudness that an average listener with normal hearing can detect.

32 / 64

Sound Intensity Level: Decibels

140 DB	Gunshot, Jet Engine at Takeoff <i>IMMEDIATE DANGER TO HEARING</i>
125 DB	Air Raid Siren, Firecracker <i>PAIN THRESHOLD</i>
120 DB	Rock Concert, Sandblasting <i>RISK OF HEARING DAMAGE IN 7 MINUTES</i>
115 DB	Baby's Cry, Jet Ski <i>RISK OF HEARING DAMAGE IN 15 MINUTES</i>
110 DB	Snowmobile in Driver's Seat <i>RISK OF HEARING DAMAGE IN 30 MINUTES</i>
105 DB	Jackhammer, Helicopter <i>RISK OF HEARING DAMAGE IN 1 HOUR</i>
100 DB	Chain Saw, Stereo Headphones <i>RISK OF HEARING DAMAGE IN 2 HOURS</i>
95 DB	Motorcycle, Power Saw <i>RISK OF HEARING DAMAGE IN 4 HOURS</i>
90 DB	Lawnmower, Truck Traffic <i>RISK OF HEARING DAMAGE IN 8 HOURS</i>
85 DB	Beginning of OSHA Regulations
70 DB	Busy traffic, Vacuum Cleaner
60 DB	Conversation, Dishwasher
40 DB	Quiet Room



1

¹OSHA: Occupational Safety and Health Act

33 / 64

Sound Intensity Level: Decibels

Effects of Ultrasound:

Although Ultrasound cannot be heard by humans, at high decibels it can still cause direct damage to human ears. Ultrasound in excess of 120 decibels may cause Hearing damage. Exposure to 155 decibels causes heat levels that are harmful to the body. 180 decibels may even cause death.

Check Your Understanding 16

If two people talk simultaneously and each creates an intensity level of 65 dB at a certain point, does the total intensity level at this point equal 130 dB?

Check Your Understanding 17

Two observation points are located at distances r_1 and r_2 from a source of sound. The sound spreads out uniformly from the source, and there are no reflecting surfaces in the environment. The sound intensity level at distance r_2 is 6 dB less than the level at distance r_1 . (a) What is the ratio I_2/I_1 of the sound intensities at the two distances? (b) What is the ratio r_2/r_1 of the distances?

35 / 64

Problem 52

A typical adult ear has a surface area of $2.1 \times 10^{-3} \text{ m}^2$. The sound intensity during a normal conversation is about $3.2 \times 10^{-6} \text{ W/m}^2$ at the listener's ear. Assume that the sound strikes the surface of the ear perpendicularly. How much power is intercepted by the ear?

36 / 64

Problem 61.

Deep ultrasonic heating is used to promote healing of torn tendons. It is produced by applying ultrasonic sound over the affected area of the body. The sound transducer (generator) is circular with a radius of 1.8 cm, and it produces a sound intensity of $5.9 \times 10^3 \text{ W/m}^2$. How much time is required for the transducer to emit 4800 J of sound energy?



37 / 64

Problem 64

The volume control on a surround-sound amplifier is adjusted so the sound intensity level at the listening position increases from 23 to 61 dB. What is the ratio of the final sound intensity to the original sound intensity?

38 / 64

Problem 65

A middle-aged man typically has poorer hearing than a middle-aged woman. In one case a woman can just begin to hear a musical tone, while a man can just begin to hear the tone only when its intensity level is increased by 7.8 dB relative to the just-audible intensity level for the woman. What is the ratio of the sound intensity just detected by the man to the sound intensity just detected by the woman?

39 / 64

Doppler Effect

The Doppler effect describes the shift in the frequency of a wave sound when the wave source and/or the observer is moving. The effect causes the sudden change in pitch noticeable in a passing siren

40 / 64

Doppler Effect

The relationship describing the Doppler Shift for a moving source moving toward stationary observer, the frequency goes up.

$$f_o = f_s \left(\frac{1}{1 - \frac{v_s}{v}} \right)$$

41 / 64

Doppler Effect

The relationship describing the Doppler Shift for a moving source moving away from stationary observer

$$f_o = f_s \left(\frac{1}{1 + \frac{v_s}{v}} \right)$$

The relationship describing the Doppler Shift for a moving observer toward a stationary source:

$$f_o = f_s \left(1 + \frac{v_o}{v} \right)$$

The relationship describing the Doppler Shift for a moving observer away from a stationary source:

$$f_o = f_s \left(1 - \frac{v_o}{v} \right)$$

42 / 64

Doppler Effect: The general case

General case: source and observer both moving

$$f_o = f_s \left(\frac{1 \pm \frac{v_o}{v}}{1 \mp \frac{v_s}{v}} \right)$$

In the numerator,

the plus sign applies when the observer moves toward the source, and the minus sign applies when the observer moves a way from the source.

In the denominator,

the minus sign applies when the source moves toward the observer, and the plus sign applies when the source moves a way from the observer.

43 / 64

← Source

→ Source

→ Source

← Source

← Observer, $\frac{+}{+}$

→ Observer, $\frac{-}{-}$

← Observer, $\frac{+}{-}$

→ Observer, $\frac{-}{+}$

44 / 64

Problem 76

A bird is flying directly toward a stationary bird-watcher and emits a frequency of 1250 Hz. The bird-watcher, however, hears a frequency of 1290 Hz. What is the speed of the bird, expressed as a percentage of the speed of sound?

45 / 64

Check Your Understanding 18

At a swimming pool, a music fan up on a diving platform is listening to a radio. As the radio is playing a tone that has a constant frequency f_s , it is accidentally knocked off the platform. Describe the Doppler effect heard by (a) the person on the platform and (b) a person down below in the water. In each case, state whether the observed frequency f_o is greater or smaller than f_s and describe how f_o changes (if it changes) as the radio falls.

Check Your Understanding 19

When a car is at rest, its horn emits a frequency of 600 Hz. A person standing in the middle of the street with this car behind him hears the horn with a frequency of 580 Hz. Does he need to jump out of the way?

46 / 64

Check Your Understanding 20

A source of sound produces the same frequency under water as it does in air. This source has the same velocity in air as it does under water. Consider the ratio f_o/f_s of the observed frequency f_o to the source frequency f_s . Is this ratio greater in air or under water when the source (a) approaches and (b) moves away from the observer?

Check Your Understanding 21

Two cars, one behind the other, are traveling in the same direction at the same speed. Does either driver hear the other's horn at a frequency that is different from the frequency heard when both cars are at rest?

47 / 64

Check Your Understanding 22

When a truck is stationary, its horn produces a frequency of 500 Hz. You are driving your car, and this truck is following behind. You hear its horn at a frequency of 520 Hz. (a) Refer to Equation 16.15 and decide which algebraic sign should be used in the numerator and which in the denominator. (b) Which driver, if either, is driving faster?

48 / 64

From subsonic speeds to hypervelocity

Regime	Subsonic	Transonic	Sonic	Supersonic	Hypersonic	Hypervelocity
Mach number	< 0.8	$[0.8 - 1.3)$	1.0	$[1.3 - 5.0)$	$[5.0 - 10)$	≥ 10.0

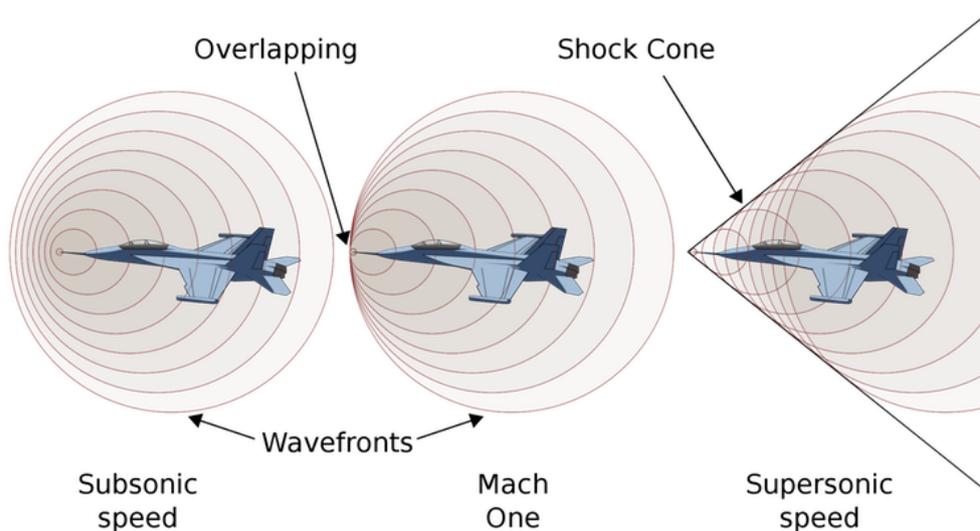
At transonic speeds, the flow field around the object includes both sub- and supersonic parts.

49 / 64

Supersonic speeds, shock waves

When the source travels faster than the speed of sound, a sonic boom occurs as the result of the piling up of compressional wavefronts along the conical edge of the wave pattern. These compressional wavefronts pile up and interfere to produce a very high pressure zone.

a shock wave carries energy and can propagate through a medium but is characterized by an abrupt, nearly discontinuous, change in pressure, temperature, and density of the medium.



50 / 64

Sound Waves: Transsonic

51 / 64

Sound Waves: Supersonic

52 / 64

Shock waves produced by the wings of Russian M25 jet.



53 / 64

The physics of ultrasonic imaging.

- The transducer probe is the main part of the ultrasound machine.
- The transducer probe makes the sound waves and receives the echoes. It is, so to speak, the mouth and ears of the ultrasound machine.
- The transducer probe generates and receives sound waves using a principle called the piezoelectric (pressure electricity) effect.

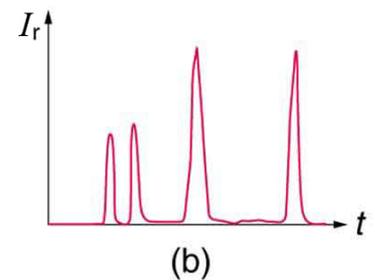
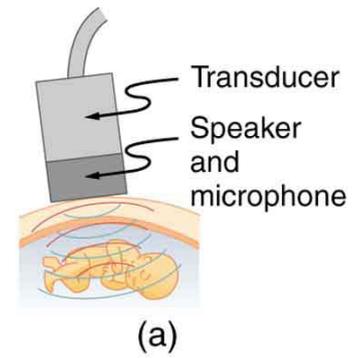


54 / 64

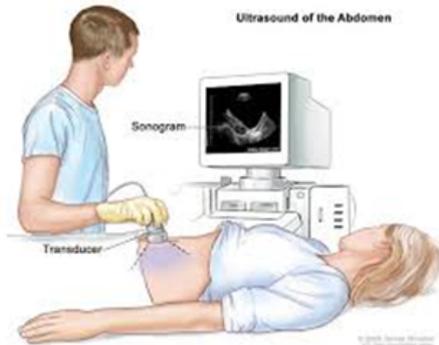


The physics of ultrasonic imaging.

- The ultrasound machine transmits high-frequency (1 to 5 megahertz) sound pulses into the body using a probe.
- The sound waves travel into the body and hit a boundary between tissues (e.g. between fluid and soft tissue, soft tissue and bone).
- Some of the sound waves get reflected back to the probe, while some travel on further until they reach another boundary and get reflected.
- The reflected waves are picked up by the probe and relayed to the machine.
- The machine calculates the distance from the probe to the tissue or organ (boundaries) using the speed of sound in tissue (1,540 m/s) and the time of the each echo's return (usually on the order of millionths of a second).
- The machine displays the distances and intensities of the echoes on the screen, forming a two dimensional image like the one shown below.



In a typical ultrasound, millions of pulses and echoes are sent and received each second. The probe can be moved along the surface of the body and angled to obtain various views.

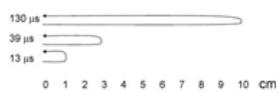
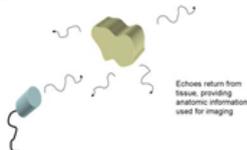


Physics of Ultrasound

How to Get Positional Information?

• Range equation: $c = \frac{2d}{t}$

US pulse interacts with tissue





Ultrasound Imaging: Benefits/Risks.

Ultrasound imaging has been used for over 20 years and has an excellent safety record. It is based on non-ionizing radiation, so it does not have the same risks as X-rays or other types of imaging systems that use ionizing radiation.

Although ultrasound imaging is generally considered safe when used prudently by appropriately trained health care providers, ultrasound energy has the potential to produce biological effects on the body. **Ultrasound waves can heat the tissues slightly. In some cases, it can also produce small pockets of gas in body fluids or tissues (cavitation).**

The long-term consequences of these effects are still unknown. Because of the particular concern for effects on the fetus, organizations such as the AMERICAN INSTITUTE OF ULTRASOUND IN MEDICINE have advocated prudent use of ultrasound imaging in pregnancy. Furthermore, the use of ultrasound solely for non-medical purposes such as obtaining fetal 'keepsake' videos has been discouraged. Keepsake images or videos are reasonable if they are produced during a medically-indicated exam, and if no additional exposure is required.

57 / 64



The physics of the cavitron ultrasonic surgical aspirator.

Neurosurgeons use a device called a **Cavitron Ultrasonic Surgical Aspirator (CUSA)** to remove brain tumors.

- Ultrasonic sound waves cause the slender tip of the CUSA probe (see Figure 16.34) to vibrate at approximately 23 kHz.
- The probe shatters any section of the tumor that it touches, and the fragments are flushed out of the brain with a saline solution.
- Because the tip of the probe is small, the surgeon can selectively remove small bits of malignant tissue without damaging the surrounding healthy tissue.

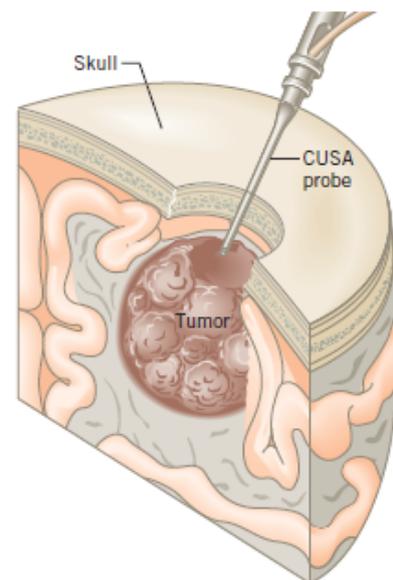


Figure 16.34 Neurosurgeons use a cavitron ultrasonic surgical aspirator (CUSA) to “cut out” brain tumors without adversely affecting the surrounding healthy tissue.

58 / 64



Sound waves used for deep brain surgery.

Focused Ultrasound Waves Eliminate Tremors:

A new ultrasound device, used in conjunction with magnetic resonance imaging (MRI), allows neurosurgeons to precisely burn out small pieces of malfunctioning brain tissue without cutting the skin or opening the skull.

- The researchers now aim to test it in patients with other disorders, such as Parkinson's disease.
- The idea behind FUSA (Focused Ultrasound Ablation) is to focus a thousand different waves of ultrasound at a single spot in the brain to burn, or ablate, specific brain tissue involved in the muscle movements associated with tremors.
- The ultrasonic waves enter directly through the skin and the waves causes localized heating, leading to a temperature of about $56\text{ }^{\circ}\text{C}$ (normal body temperature is $37\text{ }^{\circ}\text{C}$, which is sufficient to kill abnormal cells. The killed cells are eventually removed by the body's natural processes.



59 / 64



The physics of the Doppler flow meter.

The Doppler flow meter is a particularly interesting medical application of the Doppler effect. This device measures the speed of blood flow, using transmitting and receiving elements that are placed directly on the skin

- The transmitter emits a continuous sound whose frequency is typically about 5 MHz.
- When the sound is reflected from the red blood cells, its frequency is changed in a kind of Doppler effect because the cells are moving.
- The receiving element detects the reflected sound, and an electronic counter measures its frequency.
- From the change in frequency the speed of the blood flow can be determined. Typically, the change in frequency is around 600 Hz for flow speeds of about 0.1 m/s.

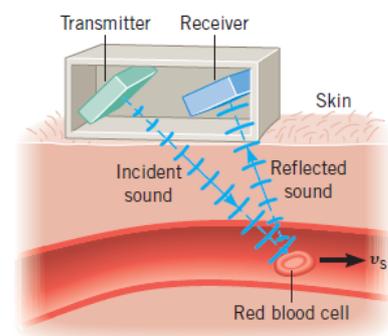


Figure 16.35 A Doppler flow meter measures the speed of red blood cells.

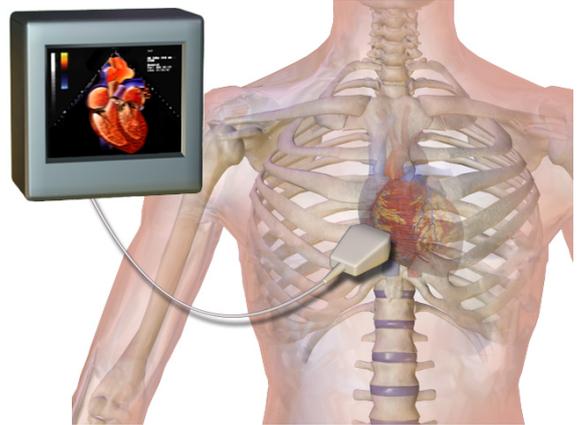
The Doppler flow meter can be used to locate regions where blood vessels have narrowed, since greater flow speeds occur in the narrowed regions.

60 / 64

Echocardiogram.

A cardiac ultrasound, or echocardiogram, is a diagnostic test used to view the structures of the beating heart such as the chambers or valves.

- In this procedure, a microphone-like device called a transducer is placed on the chest wall.
- This device captures moving pictures of the heart using ultrasound waves that is used to evaluate your heart's function.
- It can also evaluate blood flow and pressures within the heart with a special technique called Doppler Echocardiography



61 / 64

Kidney Stone Treatment: Shock Wave Lithotripsy.

Shock Wave Lithotripsy (SWL) is the most common treatment for kidney stones in the U.S. Shock waves from outside the body are targeted at a kidney stone causing the stone to fragment. The stones are broken into tiny pieces. It is sometimes called ESWL: Extracorporeal Shock Wave Lithotripsy

These are what the words mean:

extracorporeal: from outside the body

shock waves: pressure waves

lithotripsy (the Greek roots of this word are "litho" meaning stone, "tripsy" meaning crushed)

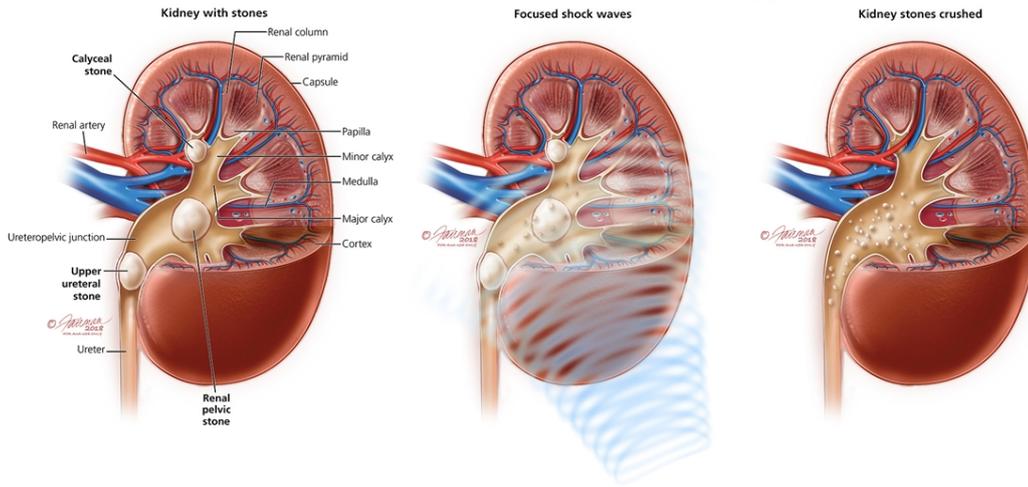
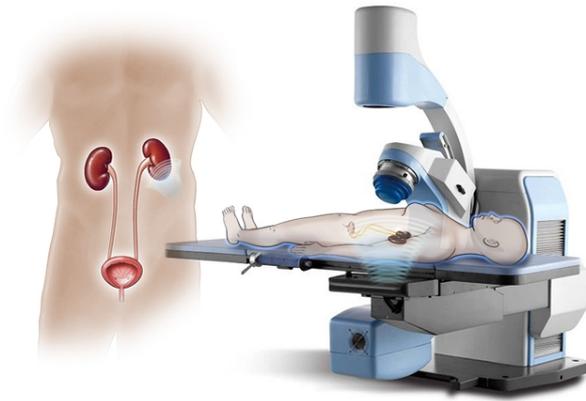
SWL describes a nonsurgical technique for treating stones in the kidney or ureter (the tube going from the kidney to the bladder) using high-energy shock waves. Stones are broken into "stone dust" or fragments that are small enough to pass in urine. If large pieces remain, another treatment can be performed

62 / 64



Kidney Stone Treatment: Shock Wave Lithotripsy.

KIDNEY: ESWL



63 / 64

Homework Problems: 1, 3, 7, 14, 33, 40, 53, 64, 79

The End

64 / 64

Electromagnetic Waves (Chapter 24)

- 1 The Nature of Electromagnetic Waves
- 2 Production of EM wave by a half wave antenna
- 3 Electromagnetic Spectrum
- 4 Detection of EM waves
- 5 The physics of wireless capsule endoscopy
- 6 Polarization of Light
- 7 A Polarized 3D System
- 8 Biological Effects Non-Ionizing Radiation
 - Ionizing vs. Non-ionizing Radiation
 - Ultra Violet Radiation and its Biological Effects
 - Mobile Communication- Ultra High Frequency (UHF) radiowaves
 - Biological Effects of Radiofrequency Fields

1 / 52

The Nature of Electromagnetic Waves

Electromagnetic radiation

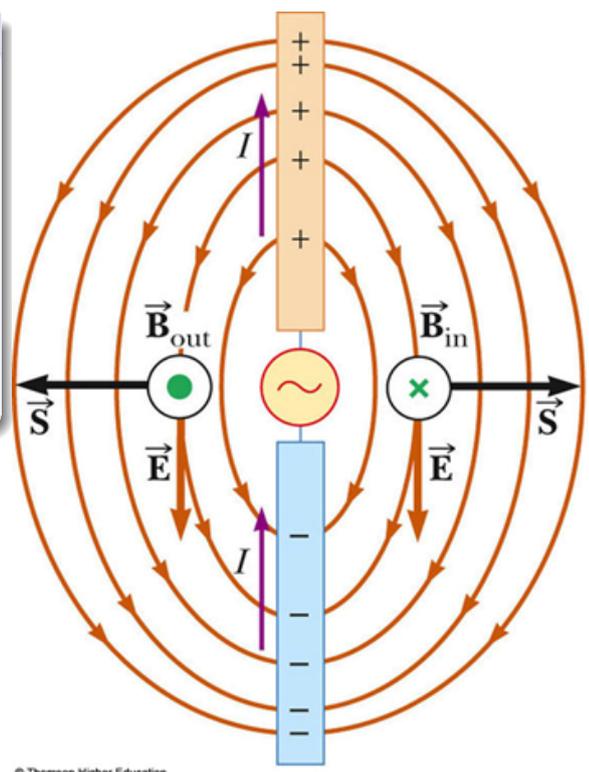
A great Scottish physicist James Maxwell (1831-1879) showed that the fluctuation of the **electric field** and **magnetic field** together can form a propagating EM wave.

The fundamental mechanism responsible for this radiation is the acceleration of a charged particle. Whenever a charged particle accelerates, it must radiate energy.

Production of EM wave by an antenna

The AC generator forces charges to accelerate back and forth between the two rods. Oscillating charges will produce electromagnetic waves

Both electric and magnetic fields exist near the antenna and together are called the near field this field decreases rapidly to zero with increasing distance from the antenna.



2 / 52

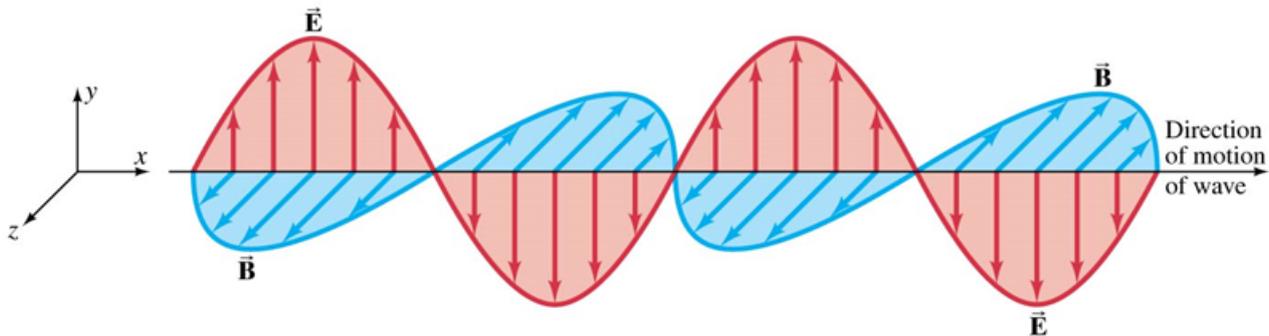
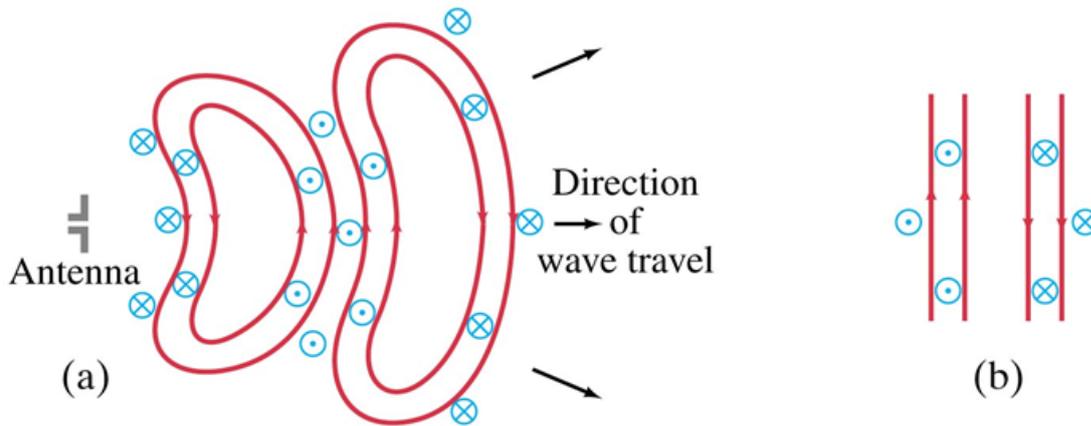


Figure: EM radiation far from the antenna. It is clear that the wave is a transverse wave. The electric and magnetic waves are perpendicular to each other, and to the direction of propagation.

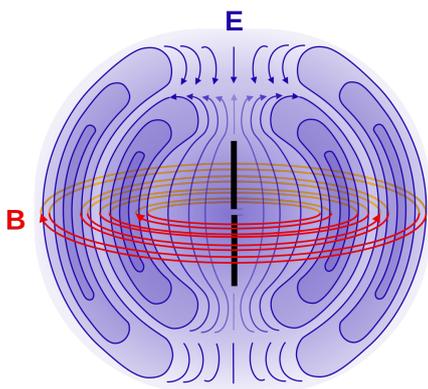


Figure: Far field radiation from a dipole antenna

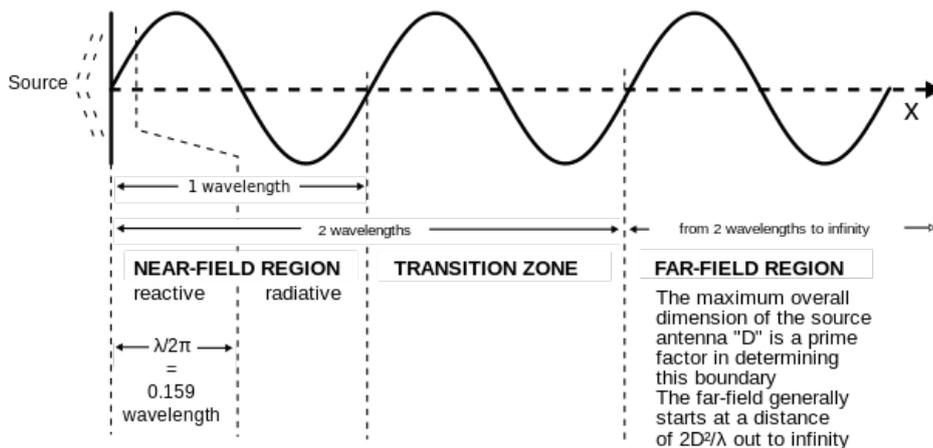


Figure: Radiation field characteristics

Electromagnetic Radiation: Far Field

The source of the radiation found far from the antenna is the continuous induction of an electric field by the time-varying magnetic field and the induction of a magnetic field by a time-varying electric field

The electric and magnetic field produced in this manner are **in phase with each other and vary as $1/r$**

The result is the outward flow of energy at all times

5 / 52

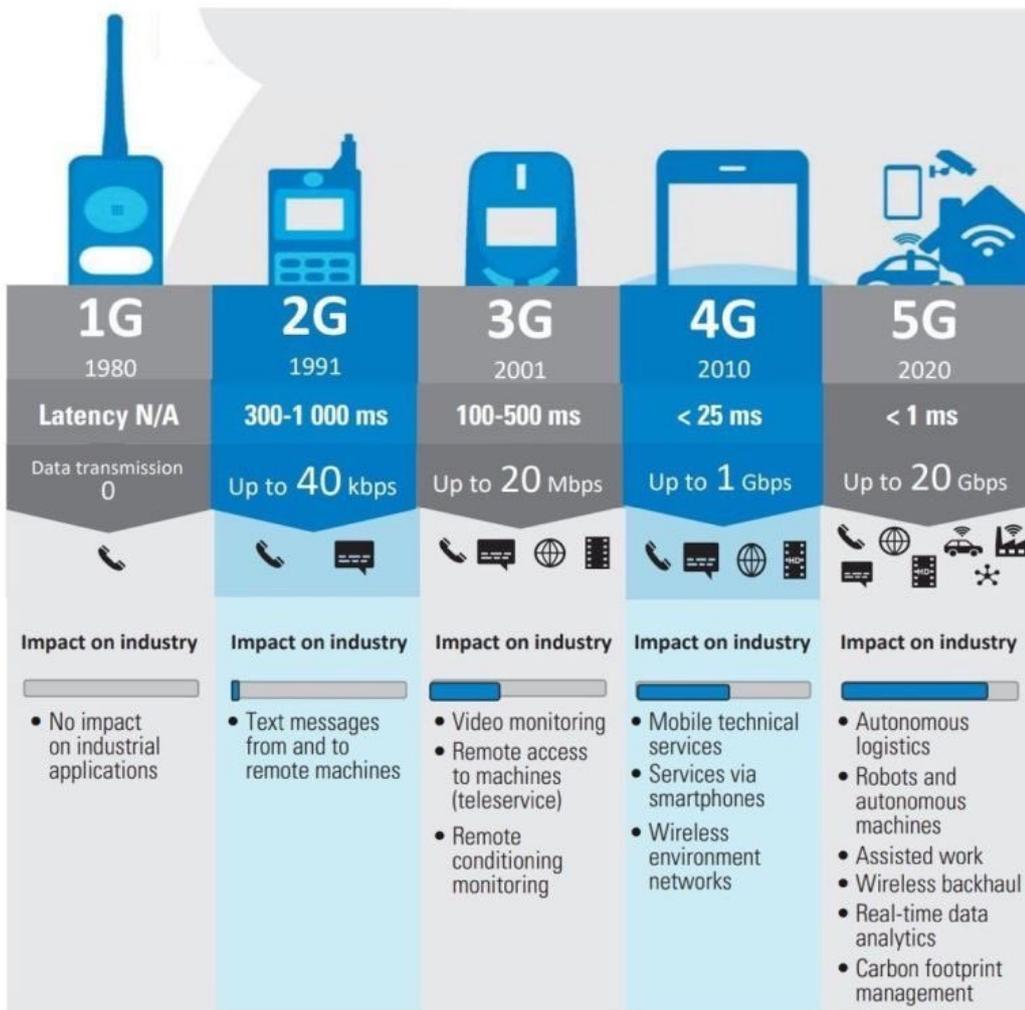
half-wave dipole antenna

A half-wave antenna consists of two lengths of wire rod, or tubing, each $1/4$ wavelength long at a certain frequency. It is the basic unit from which many complex antennas are constructed.

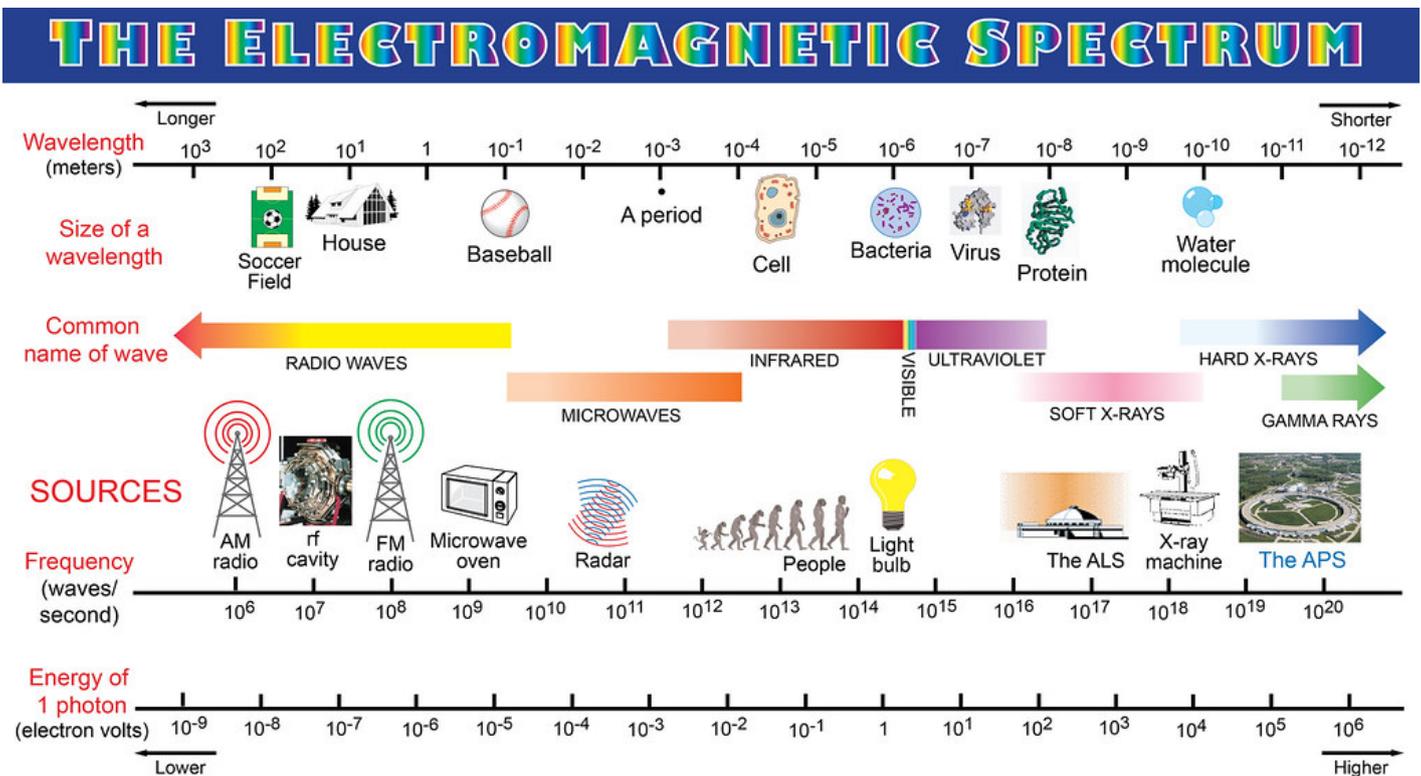
Antennas are usually arranged in groups of three, with one antenna in each group used to transmit signals to mobile units, and the other two antennas used to receive signals from mobile units.



6 / 52



Electromagnetic Spectrum



Electromagnetic waves can have any wavelength; we have given different names to different parts of the electromagnetic spectrum.

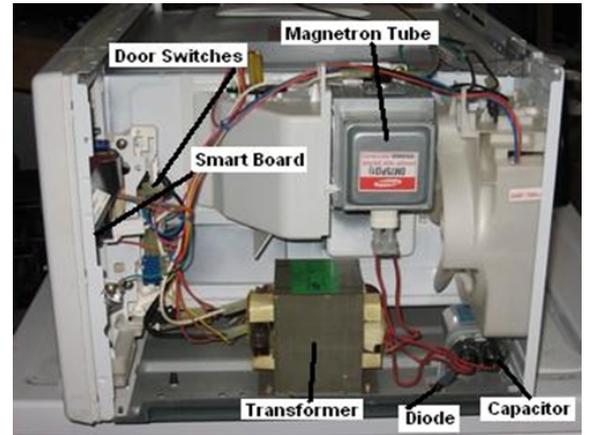
When Maxwell calculated the speed of propagation of electromagnetic waves, he found:

Microwave Oven

A microwave oven (also commonly referred to as a microwave) is an electric oven that heats and cooks food by exposing it to electromagnetic radiation in the microwave frequency range.

- This induces polar molecules in the food to rotate and produce thermal energy in a process known as dielectric heating.
- Microwave ovens heat foods quickly and efficiently because excitation is fairly uniform in the outer 25-38 mm (1-1.5 inches) of a homogeneous, high water content food item.

Modern microwave ovens operate at the frequency 2.450 GHz. By federal regulation, microwave ovens are limited to 5 milliwatts (mW) of microwave radiation per square centimeter at approximately 2 inches from the oven surface.

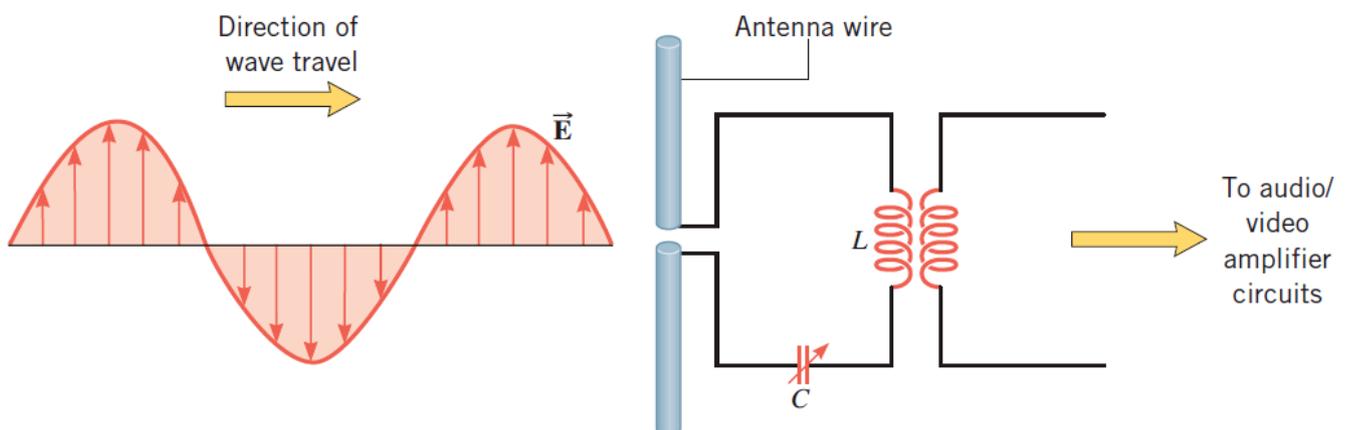


This is a layout of a basic countertop microwave. Please note that your layout may differ but the components should look very much like the ones in the picture.

9 / 52

Detection of EM waves

Detecting the electric field



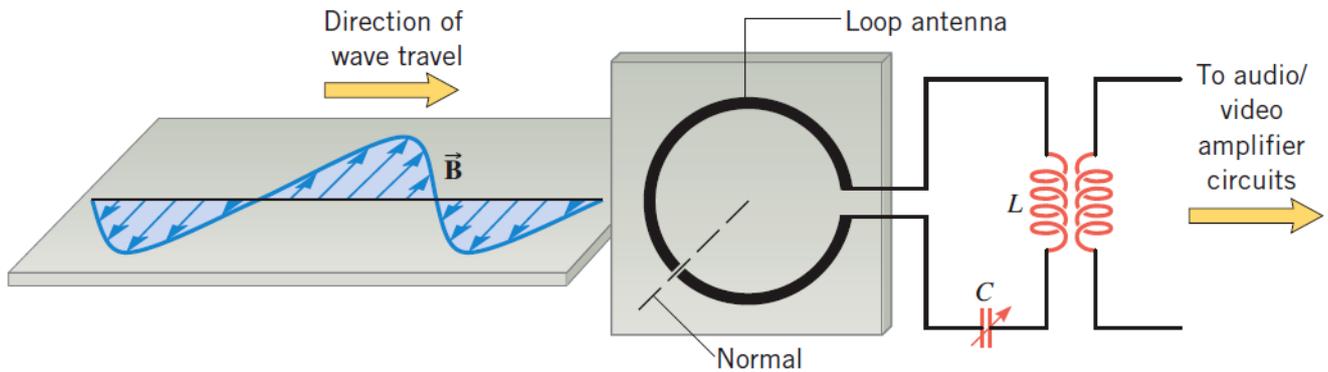
An EM wave can be detected with a receiving antenna wire that is parallel to the electric field

$$f = \frac{1}{2\pi} \frac{1}{\sqrt{LC}}$$

10 / 52

Detection of EM waves

Detecting the magnetic field



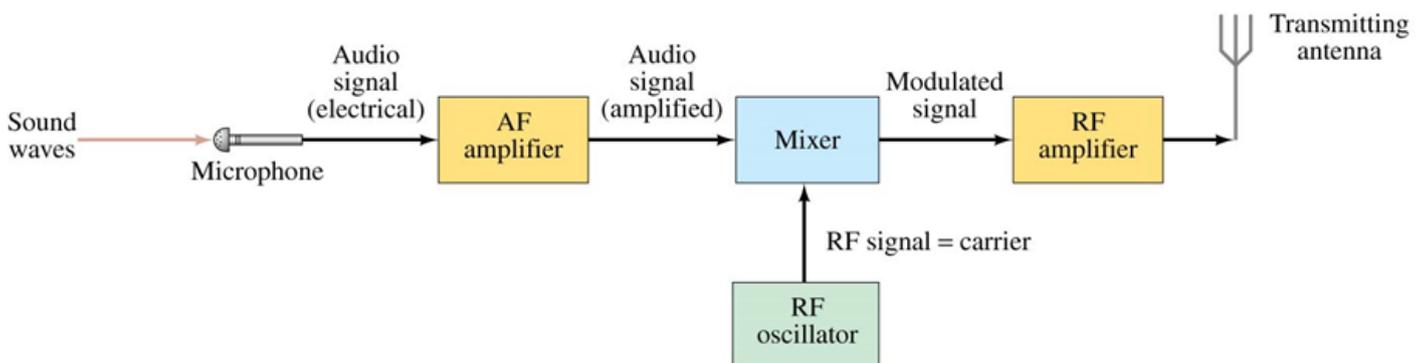
To detect the magnetic field of an EM wave, a receiving antenna in the form of loop can be used. The normal to the plane of the loop should be parallel to the magnetic field for best reception.

$$f = \frac{1}{2\pi} \frac{1}{\sqrt{LC}}$$

11 / 52

Radio and Television: Wireless Communication

Transmission



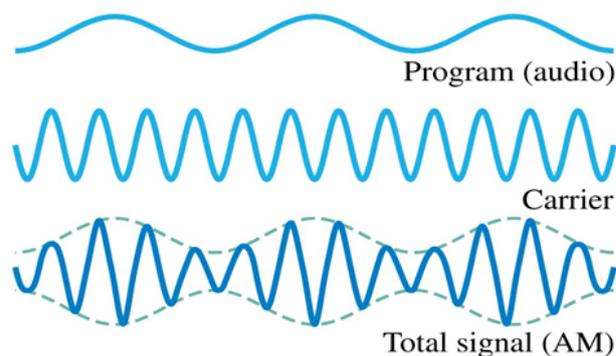
This figure illustrates the process by which a radio station transmits information. The audio signal is combined with a carrier wave

12 / 52

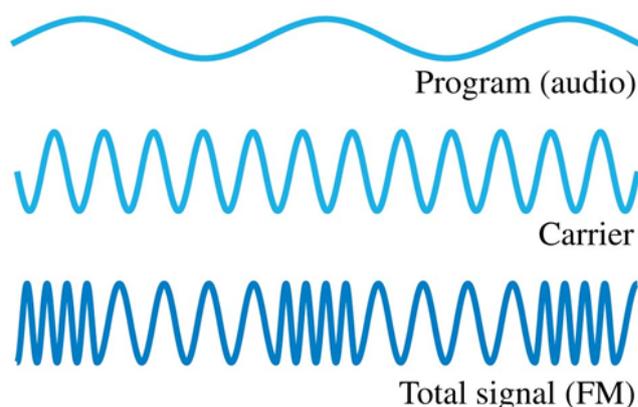
Radio and Television: Wireless Communication

The mixing of signal and carrier can be done two ways.

First, by using the signal to modify the amplitude of the carrier (AM):
Amplitude Modulation



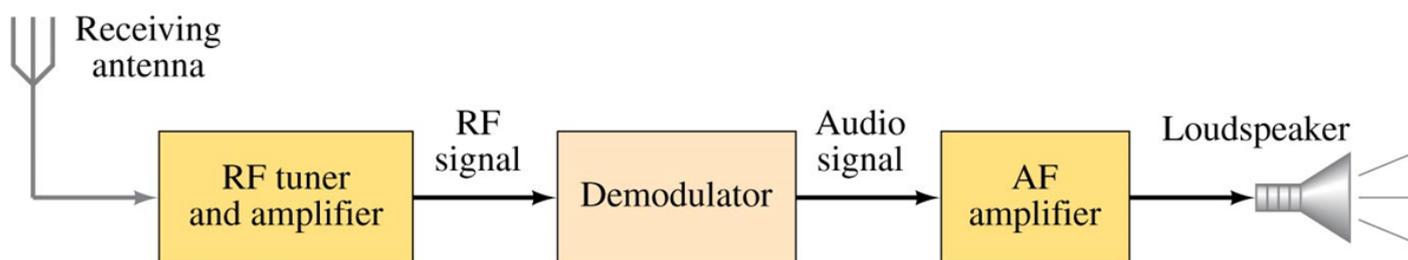
Second, by using the signal to modify the frequency of the carrier (FM):
Frequency Modulation



13 / 52

Radio and Television: Wireless Communication

Receiving



This figure illustrates the receiving end, the wave is received, demodulated, amplified, and sent to a loudspeaker

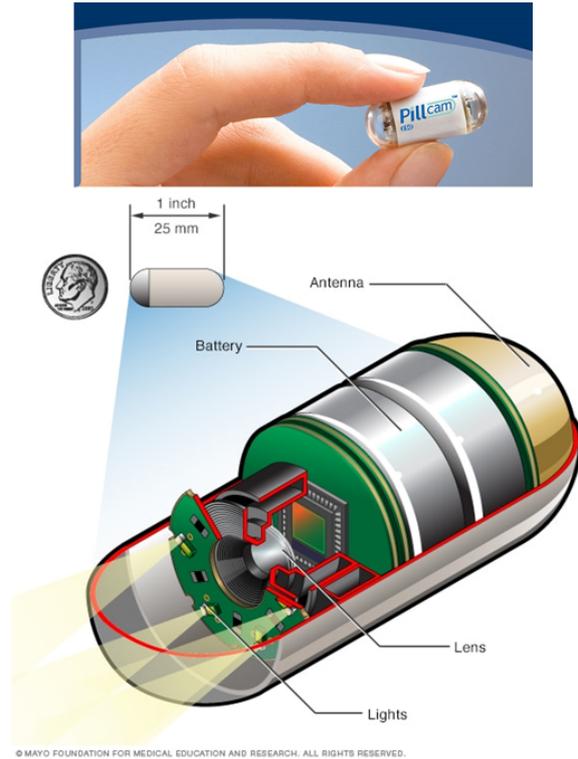
14 / 52



The physics of wireless capsule endoscopy.

What is Capsule Endoscopy?

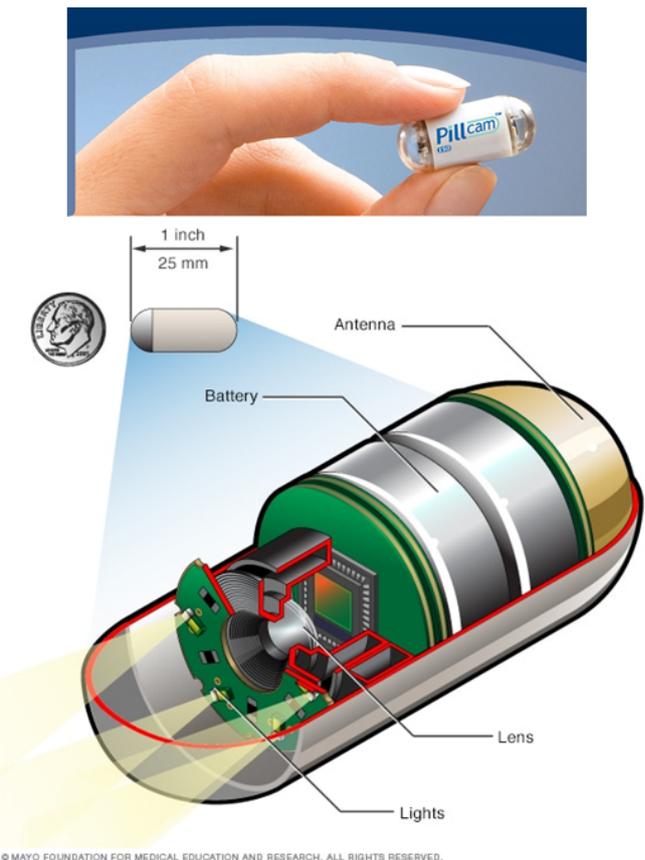
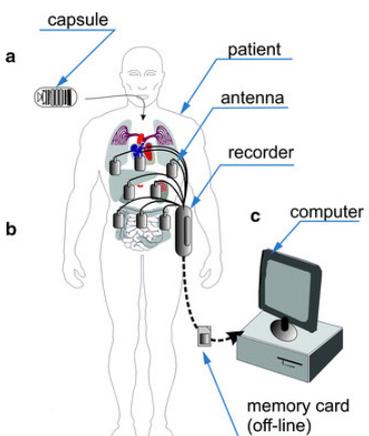
- A way to record images of the digestive tract through a small camera in the pill by using broadcasting and receiving of radio waves (wireless)
- It is the size and shape of a pill. (11 × 26mm)
- Adopted in the U.S. Approved by the U.S Food and Drug Administration 2001
- Capsule endoscopy helps doctors see inside your small intestine - an area that isn't easily reached with more-traditional endoscopy procedures.



The physics of wireless capsule endoscopy.

What is Capsule Structure?

- Contains Lens
- 4 emitting diodes
- Color camera
- 2 batteries
- Radio Frequency Transmitter
- Antenna



Check Your Understanding 1

A transmitting antenna is located at the origin of an x, y, z axis system and broadcasts an electromagnetic wave whose electric field oscillates along the y axis. The wave travels along the $+x$ axis. Three possible wire loops are available for use with an LC-tuned circuit to detect this wave: (a) a loop that lies in the xy plane, (b) a loop that lies in the xz plane, and (c) a loop that lies in the yz plane. Which one of the loops will detect the wave?

Check Your Understanding 3

Why does the peak value of the emf induced in a loop antenna (see Figure 24.5) depend on the frequency of the electromagnetic wave?

17 / 52

Problem 4

FM radio stations use radio waves with frequencies from 88.0 to 108 MHz to broadcast their signals. Assuming that the inductance in Figure 24.4 has a value of 6.00×10^{-7} H, determine the range of capacitance values that are needed so the antenna can pick up all the radio waves broadcasted by FM stations.

18 / 52

Problem 11

Magnetic resonance imaging, or MRI (see Section 21.7), and positron emission tomography, or PET scanning (see Section 32.6), are two medical diagnostic techniques. Both employ electromagnetic waves. For these waves, find the ratio of the MRI wavelength (frequency 6.38×10^7 Hz) to the PET scanning wavelength (frequency 1.23×10^{20} Hz).

19 / 52

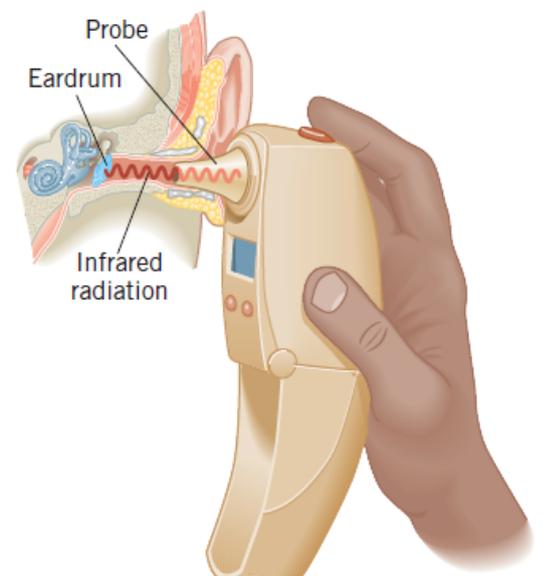
The physics of a pyroelectric ear thermometer.

The human body, like any object, radiates infrared radiation, and the amount emitted depends on the temperature of the body.

- The infrared energy falls on a thin pyroelectric crystal which develops a charge proportional to that collected energy.
- Discharging the crystal sends a current pulse through filters and conversion circuits which calculate a body temperature for the display.

The ear is one of the best places for this measurement because

- it is close to the hypothalamus, an area at the bottom of the brain that controls body temperature.
- The ear is also not cooled or warmed by eating, drinking, or breathing.

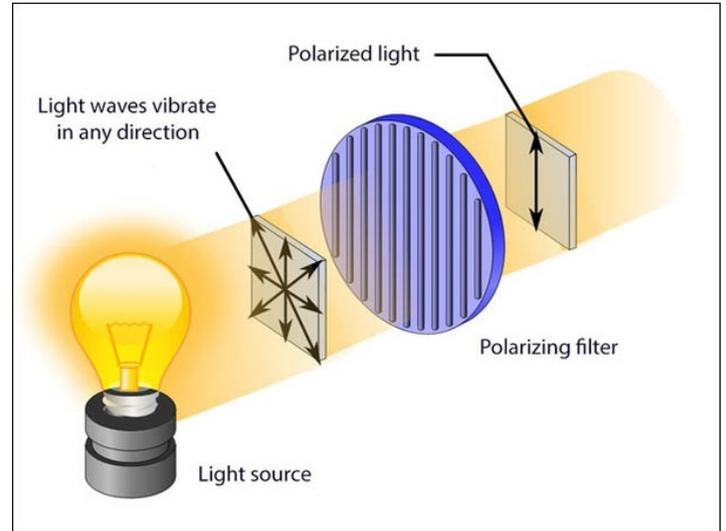


20 / 52

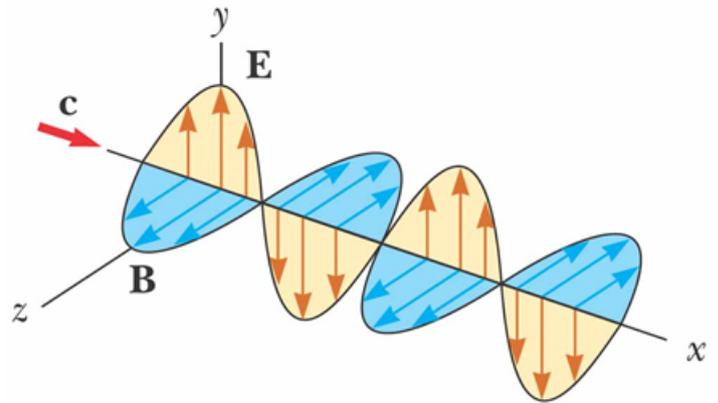
Polarization of Light

Unpolarized light.

Such as light emanating from sources such as sun or light bulb, the electric field vibrates in all directions at right angles to the direction of propagation.



Polarized light waves are light waves in which the vibrations occur in a single plane. The process of transforming unpolarized light into polarized light is known as polarization.



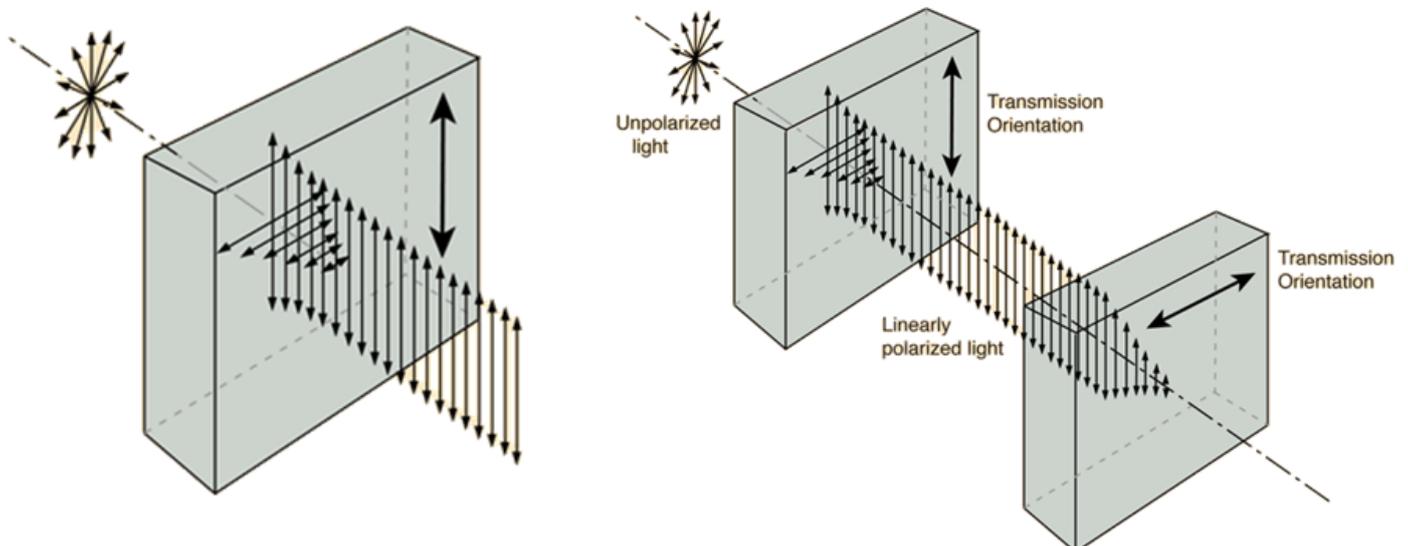
©2004 Thomson - Brooks/Cole

21 / 52

Polarization by selective absorption (using polaroid films)

The most common technique for polarizing light.

Uses a material that transmits waves whose electric field vectors lie in the plane parallel to a certain direction and absorbs waves whose electric field vectors are in all other directions.



22 / 52

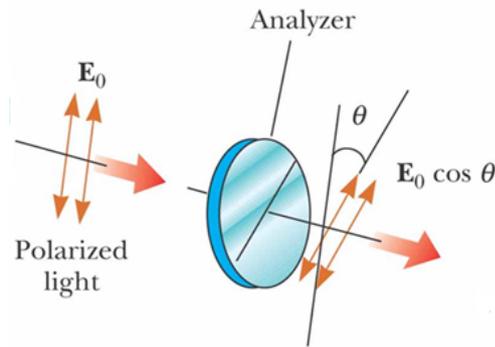
Polarization: Malus Law

For initially polarized light:

$$E_{\text{transmitted}} = E_0 \cos \theta$$

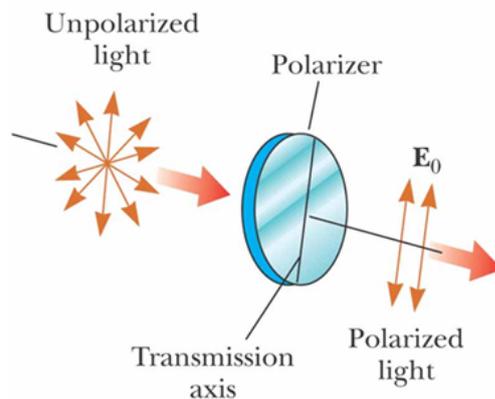
the intensity $I \propto E^2$,

$$I_{\text{transmitted}} = I_0 \cos^2 \theta$$



For initially unpolarized light:

$$I_{\text{transmitted}} = \frac{I_0}{2}$$



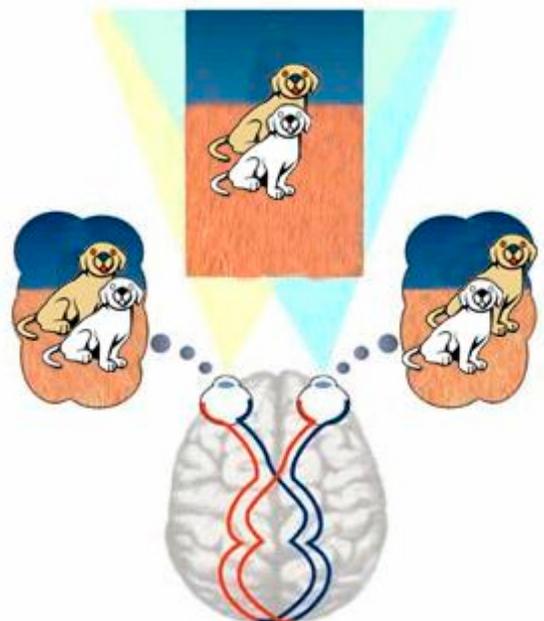
©2004 Thomson - Brooks/Cole

23 / 52

Polarization by selective absorption (Example)

How we see 3D?

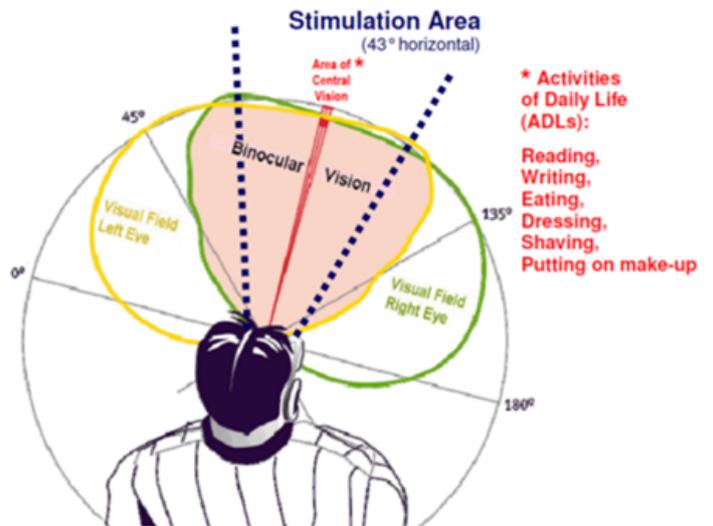
- Because your eyes are separated on your face, each retina produces a slightly different image.
- That difference in images is a direct result of the depth of the objects that we are looking at.
- When those two images are assembled in your brain, they are interpreted as depth.
- Stereoscopic vision works most effectively for distances up to 5.5 meters.
- Beyond this distance, your brain starts using relative size and motion to determine depth.



24 / 52

Stereoscopic vision.

When you look straight into distance, your eyes are parallel to each other. The areas seen with the right and with the left eye overlap to a certain extent. With the left eye you see not only what happens at the left side of your body, but also what happens at the center and partially at the right side and vice versa. The largest part of the visual field is seen binocularly, in other words with two eyes. Since our eyes are up to $2\frac{1}{2}$ inches apart from each other, we receive two different pictures of our environment from the left and from the right eye.



The brain “computes” the spatial information from the difference between the two pictures on the retina and creates a joint overall image, which provides extra information about distance to an object. This process is called stereoscopic vision

25 / 52

The physics of IMAX 3-D films.

3D stereoscopic imaging is as simple as producing two slightly different images - the same as your eyes would produce - and then showing each eye only one of those images. This can be done with light-refraction, color-filtering, or light polarization.

An exciting application of crossed polarizers is used in viewing IMAX 3-D movies.

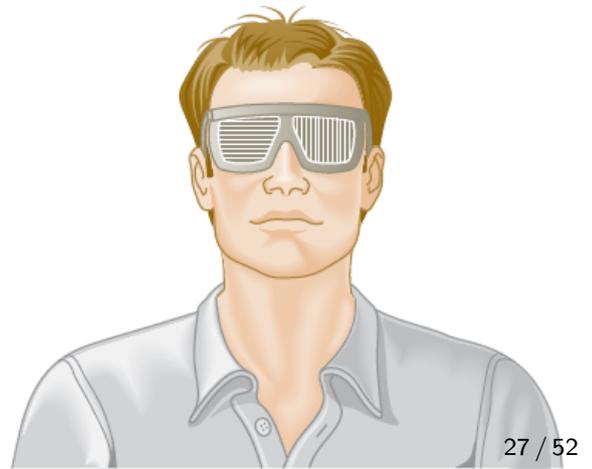
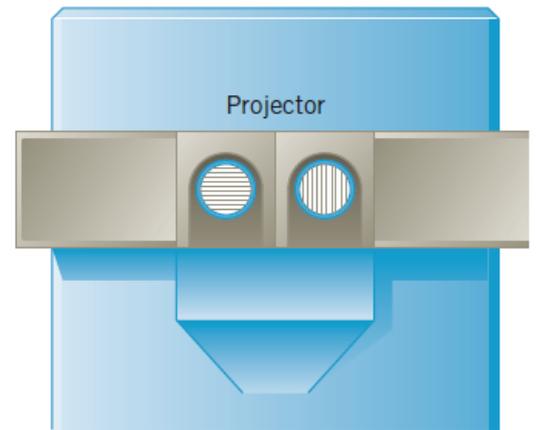
- These movies are recorded on two separate rolls of film, using a camera that provides images from the two different perspectives that correspond to what is observed by human eyes and allow us to see in three dimensions.
- The camera has two apertures or openings located at roughly the spacing between our eyes.



26 / 52

The physics of IMAX 3-D films.

- The films are projected using a projector with two lenses, as Figure indicates.
- Each lens has its own polarizer, and the two polarizers are crossed (see the drawing).
- Viewers watch the action on-screen using glasses with corresponding polarizers for the left and right eyes, as the drawing shows.
- Because of the crossed polarizers the left eye sees only the image from the left lens of the projector, and the right eye sees only the image from the right lens.
- Since the two images have the approximate perspectives that the left and right eyes would see in reality, the brain combines the images to produce a realistic 3-D effect.



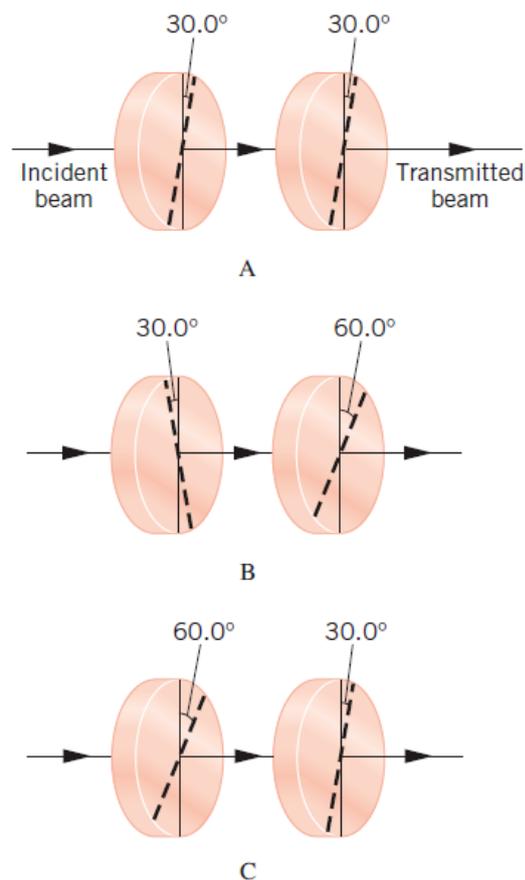
Problem 39

Unpolarized light whose intensity is 1.10 W/m^2 is incident on the polarizer in Figure 24.21. (a) What is the intensity of the light leaving the polarizer? (b) If the analyzer is set at an angle of 75° with respect to the polarizer, what is the intensity of the light that reaches the photocell?

29 / 52

Problem 40

The drawing shows three polarizer/analyzer pairs. The incident light beam for each pair is unpolarized and has the same average intensity of 48 W/m^2 . Find the average intensity of the transmitted beam for each of the three cases (A, B, and C) shown in the drawing.



Problem 40

30 / 52



Biological Effects Non-Ionizing Radiation.

This section discuss the non-ionizing radiation and its biological effects/risks. The sources of this material are:

THE FEDERAL COMMUNICATIONS COMMISSION, THE DEPARTMENT OF HEALTH AND HUMAN SERVICES: CENTERS FOR DISEASE CONTROL AND PREVENTION, AND THE ENVIRONMENT PROTECTION AGENCY, USA.



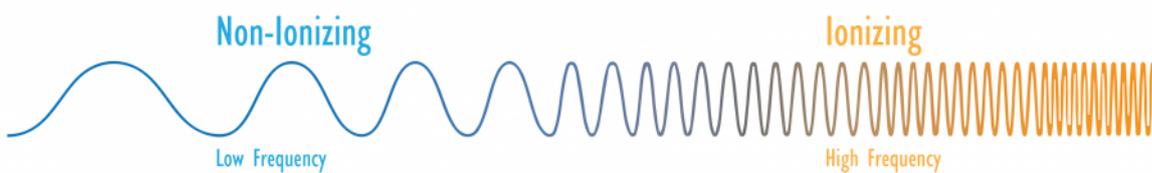
Non-ionizing radiation

Ionizing vs. Non-ionizing Radiation

Ionizing radiation: is a form of energy that acts by removing electrons from atoms and molecules of materials that include air, water, and living tissue. Ionizing radiation can travel unseen and pass through these materials.

Non-ionizing radiation: exists all around us from many sources. It is to the left of ionizing radiation on the electromagnetic spectrum in the figure below.

Electromagnetic Spectrum



Ultra violet radiation

Wave Type	UVA	UVB	UVC
Wavelength	315 – 399 nm	280 – 314 nm	100 – 279 nm
Absorption Level	Not absorbed by the ozone layer	Mostly absorbed by the ozone layer, but some does reach the Earth's surface	Completely absorbed by the ozone layer and atmosphere

All of the UVC and most of the UVB radiation is absorbed by the earth's ozone layer, so nearly all of the ultraviolet radiation received on Earth is UVA. Even though UVA radiation is weaker than UVB, it penetrates deeper into the skin and is more constant throughout the year. Since UVC radiation is absorbed by the earth's ozone layer, it does not pose as much of a risk.

33 / 52

Benefits of UV radiation

Production of vitamin D, a vitamin essential to human health. Vitamin D helps the body to absorb calcium and phosphorus from food and assists in bone development. The World Health Organization (WHO) recommends 5 to 15 minutes of sun exposure 2 to 3 times a week.

Artificial forms of UV radiation (lasers, lamps, or a combination of these devices) used to treat patients with certain diseases who have not responded to other methods of therapy.

A trained healthcare professional uses this special procedure called phototherapy to treat the following: Rickets (Rickets is the softening and weakening of bones in children, usually because of an extreme and prolonged vitamin D deficiency), Eczema.

34 / 52



Biological Effects of UV radiation: Risks.

- Sunburn is a sign of short-term overexposure, while premature aging and skin cancer are side effects of prolonged UV exposure.
- Some oral and topical medicines, such as antibiotics, birth control pills, and benzoyl peroxide products, as well as some cosmetics, may increase skin and eye sensitivity to UV in all skin types.
- Immunity decreases
- UV exposure increases the risk of potentially blinding eye diseases, cataract as shown in Figure 5, if eye protection is not used.
- Overexposure to UV radiation can lead to serious health issues, including cancer. Skin cancer is the most common cancer in the United States. Most cases of melanoma, the deadliest kind of skin cancer, are caused by exposure to UV radiation as shown in Figure 4.

35 / 52

Biological Effects of UV radiation: Risks

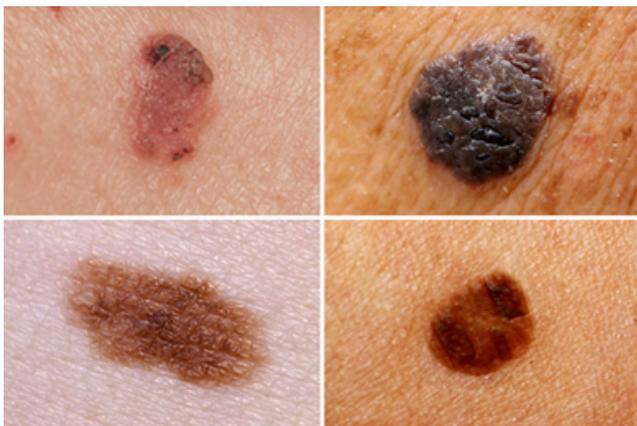


Figure: 4- Melanoma



Figure: 5- Cataract

36 / 52

Mobile Communication- Ultra High Frequency (UHF) radiowaves

- It is an electromagnetic radiation with frequencies btw. 300-3000 MHz, and $\lambda = 1 - 0.1\text{m}$
- Is non-ionizing radiation
- Is used at TV and Mobile Transmissions
- Mobile Phones work mostly under frequency 900, 1800, 1900, and 2100 MHz.
- Mobile phone is small transceiver, periodically connecting by radiowaves with Basic Mobile Station (BMS are placed on the top of hills, on the roofs, etc.) The intensity of electromagnetic radiation in a vicinity of BMS is very high and danger for body

RF radiation from mobile phones can affect the operation of sensitive electronic equipment such as aircraft navigation systems and medical equipment. This may indirectly endanger the lives of people through the failure of these electronic systems, and that is why warnings to turn mobile phones off are announced in aircraft and hospitals.

37 / 52



Biological effects of Radiofrequency Fields.

Thermal effects:

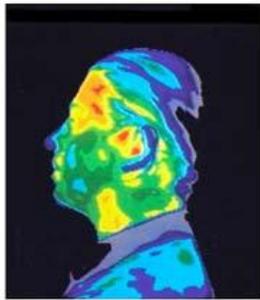
Biological effects that result from heating of tissue by RF energy are often referred to as thermal effects.

Two areas of the body, the eyes and the testes, are particularly vulnerable to RF heating because of the relative lack of available blood flow to dissipate the excess heat load.

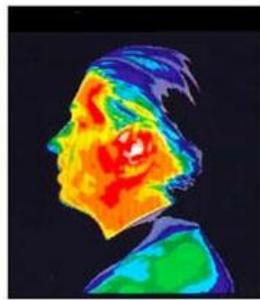
Scientists have known for a long time about the ability of RF radiation to cause heating, which can lead to severe health effects on the body such as **fatigue**, **reduced mental concentration** and **cataracts** if exposed to very high levels.

38 / 52

Thermal images of the head

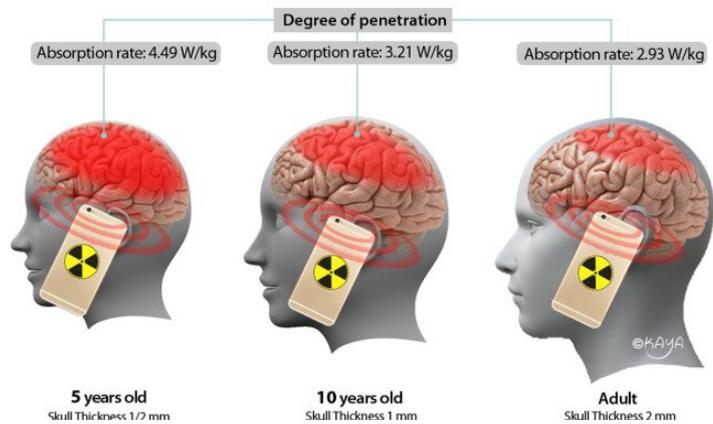


Thermographic Image of the head with no exposure to harmful cell phone radiation.



Thermographic Image of the head after a 15-minute phone call. Yellow and red areas indicate thermal (heating) effects that can cause negative health effects.

How the diffusion of radiation among different ages in the brain



39 / 52

Biological effects of Radiofrequency Fields

Non-thermal effects:

- At relatively low levels of exposure to RF radiation, the evidence for production of harmful biological effects is ambiguous and unproven.
- A number of reports have appeared in the scientific literature describing the observation of a range of biological effects resulting from exposure to low levels of RF energy. However, in most cases, further experimental research has been unable to reproduce these effects.
- It is generally agreed that further research is needed to determine the generality of such effects and their possible relevance, if any, to human health.
- In the meantime, standards-setting organizations and government agencies continue to monitor the latest experimental findings to confirm their validity and determine whether changes in safety limits are needed to protect human health

40 / 52

Can using a cell phone cause cancer?

It is unknown for sure if RF radiation from cell phones can cause health problems years later. The International Agency for Research on Cancer (IARC) has classified RF radiation as **a possible human carcinogen**. (A carcinogen is an agent that causes cancer.)

Scientists are continuing to study the possible health effects of cell phone use. For example, the World Health Organization (WHO) is currently looking into how cell phones may affect:

- Some types of tumors (a lump or growth)
- Our eyes
- Sleep
- Memory
- Headaches

41 / 52

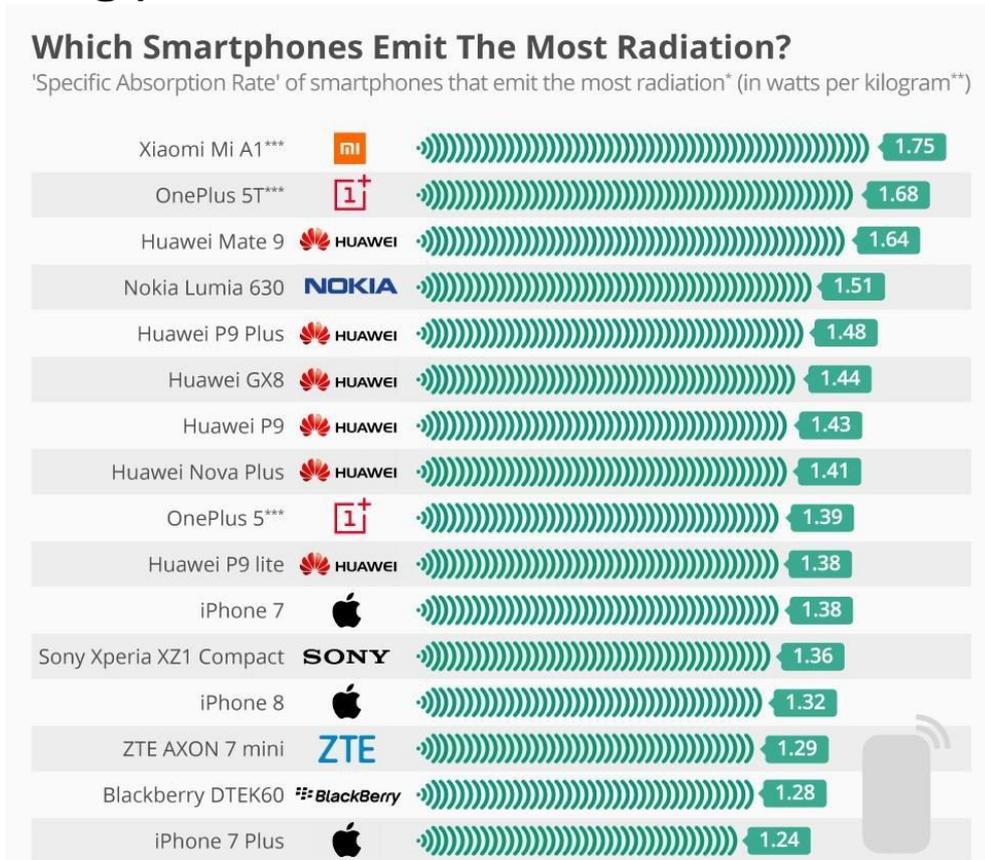
Limits for safe exposure to radiofrequency

- The FCC has adopted limits for safe exposure to radiofrequency (RF) energy.
- These limits are given in terms of a unit referred to as the **Specific Absorption Rate (SAR)**, which is a measure of the amount of radio frequency energy absorbed by the body when using a mobile phone.
- The FCC requires cell phone manufacturers to ensure that their phones comply with these objective limits for safe exposure.
- Any cell phone at or below these SAR levels (that is, any phone legally sold in the U.S.) is a safe phone, as measured by these standards. The FCC limit for public exposure from cellular telephones is an SAR level of 1.6 watts per kilogram (1.6 W/kg).

42 / 52

How to use mobiles safely?

1. Buy only phones with SAR < 1.6 W/kg: look for SAR number being placed on the box.:

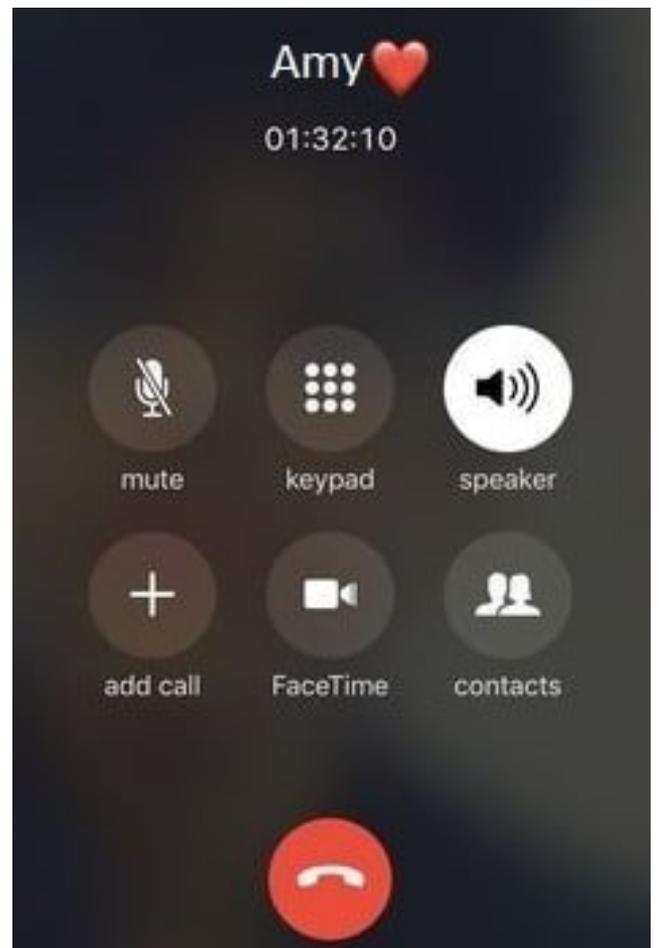


43 / 52

How to use mobiles safely?

2. Avoid long conversation:

Long conversation without using proper headphones cause heating effect on brain cells due to electromagnetic radiation. Radio Frequency radiation could penetrate human cells and damage tissues in our body over time. Long term exposure of high power RF signals could harm our brain cells, skin, ear etc. . . The short-term effect of EM radiation in individuals are different; some feel headache, tiredness and dizziness etc. . .

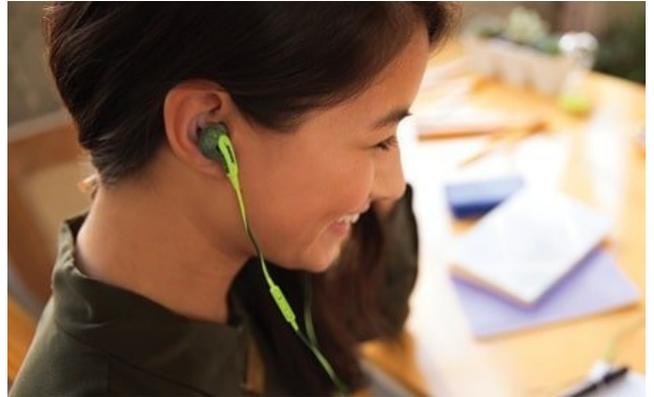


44 / 52

How to use mobiles safely?

3. Use headsets or speakerphone option:

Use of good wired or wireless headsets reduce the risk of electromagnetic radiation to brain cells. Make use of speakerphone options whenever possible. Bluetooth technology uses very low power for transmission and considered as safe way (moderate use) to use with mobile devices.



45 / 52

How to use mobiles safely?

4. Keep mobile devices away from your body:

All transmitting devices should keep away from your body. Avoid any direct contact with body and keep it inside bag or a pouch if possible. While sleeping, keep your mobile devices away from your bed and switch off mobile data and Wi-Fi options.

Cell towers continuously send ping signals to mobile devices to keep track of them whether the UE (User Equipment) are still under cell circle.



46 / 52

How to use mobiles safely?

5. Avoid calls at places with low signal reception:

In order to keep connected with mobile tower, mobile devices increase transmission power if the signal reception is poor. Avoid places where signal reception from mobile tower is very poor. Try to avoid basements, underground parking stations and in elevators due to poor signal reception. Avoid phone calls while travelling on a vehicle. Cell phones continuously send signals to maintain contact with cell towers and it could cause the mobile device to transmit high power radiation than idle condition.



47 / 52

How to use mobiles safely?

6. Keep cell phone away from children:

Children are more sensitive to RF radiation due to smaller head circumference and brain size. Studies shows that, cell phone radiation affects bone density especially in kids below age of 10 years old. Do not allow children use mobile devices unless really necessary and make sure the call length is as short as possible.



48 / 52

How to use mobiles safely?

- Buy only phones with SAR < 1.6 W/kg: look for SAR number being placed on the box.
- Do not call when driving or traveling by train (i.e. avoid making calls at all places with low signal). The lower is the signal the higher radiations from the phone.
- Do not make a call over 2-3 minutes.
- Do not touch the head with a part of phone where there is an antenna.
- Do not allow children (at least till 6 years of age) to use and make calls from mobile phones.
- Do not store the phone in a pocket of a shirt close the heart.
- Use speaker-phone more often.

49 / 52

Biological Effects of Non-Ionizing Radiation I

In 2015, 215 scientists from 41 countries communicated their alarm to the United Nations (UN) and World Health Organization (WHO). They stated that “numerous recent scientific publications have shown that electromagnetic fields affects living organisms at levels well below most international and national guidelines. More than 10,000 peer-reviewed scientific studies demonstrate harm to human health from RF radiation.

RESULTS TO DATE HAVE BEEN INCONCLUSIVE. Effects include:

- Alteration of heart rhythm
- Altered gene expression
- Altered metabolism
- Altered stem cell development
- Cancers
- Cardiovascular disease

50 / 52

Biological Effects of Non-Ionizing Radiation II

- Cognitive impairment - is when a person has trouble remembering, learning new things, concentrating, or making decisions that affect their everyday life.
- DNA damage
- Impacts on general well-being
- Increased free radicals
- Learning and memory deficits
- Impaired sperm function and quality
- Miscarriage
- Neurological damage
- Obesity and diabetes
- Oxidative stress

51 / 52

Homework Problems: 8, 17, 45, 48

The End

52 / 52

The Refraction of Light: Lenses and Optical Instruments (Chapter 26)

- 1 The Index of Refraction
- 2 Snell's Law and the Refraction of Light
- 3 Apparent Depth and Real Depth
- 4 Total Internal Reflection
- 5 Fiber Optics-Endoscope
- 6 Thin Lenses
- 7 The Human Eye
- 8 Eye Disorders

1 / 47

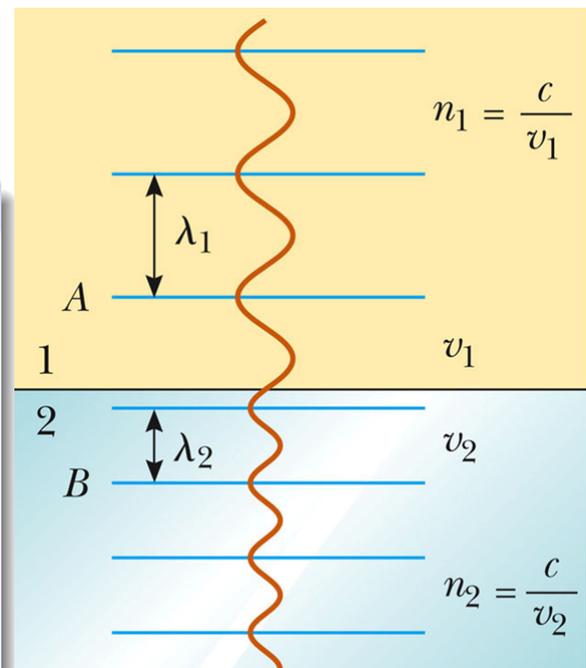
The Index of Refraction

Definition of the Index of Refraction

The index of refraction n of a material is the ratio of the speed c of light in a vacuum to the speed v of light in the material:

$$n = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in material}} = \frac{c}{v}$$

Light travels through a material with a speed that is less than the speed of light c .



© Thomson Higher Education

The frequency stays the same as the wave travels from one medium to the other, but speed and wavelength will change

2 / 47

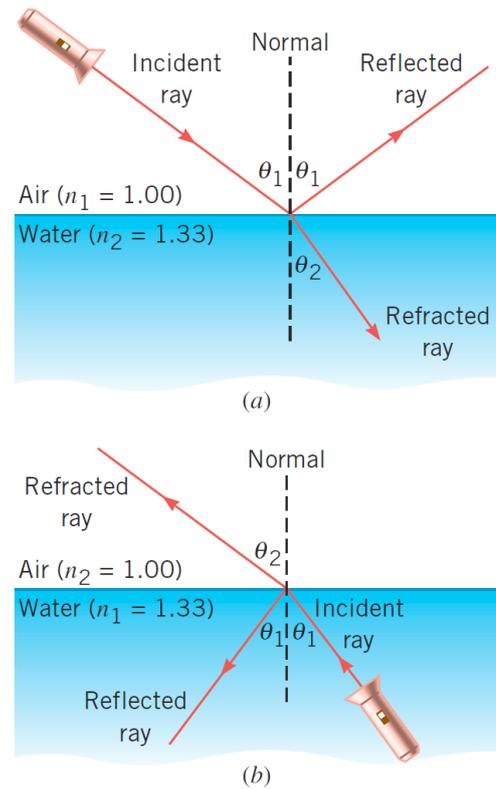
Snell's Law and the Refraction of Light

Snell's Law of Refraction

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

1. When light travels from a medium where the refractive index is smaller into a medium where it is larger, the refracted ray is bent toward the normal, as in Figure
2. When light travels from a medium where the refractive index is larger into a medium where it is smaller, the refracted ray is bent away from the normal, as in Figure

Refracted and incident rays obey the principle of reversibility.



the incident ray and the normal to the interface between the materials all lie in the same plane.

3 / 47

Apparent depth and real depth

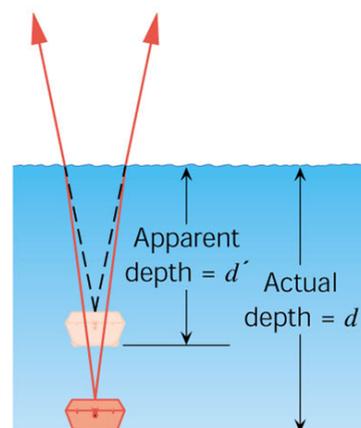
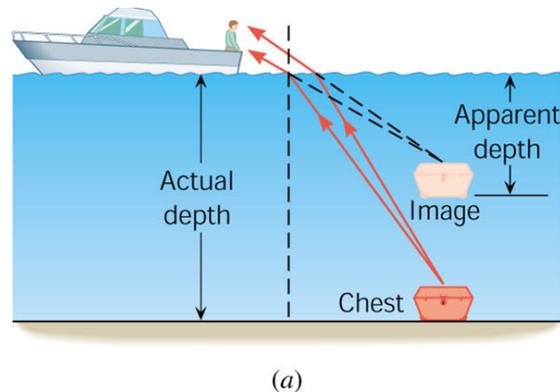
Real depth is the actual depth from the surface, whereas apparent depth is the depth which is visible to human eye this is due to refraction of light in different medium where object seems higher than it's position.

An object lying below water appears to be closer to the surface than it actually is.

Apparent depth when an observer is directly above object is

$$d' = d \left(\frac{n_2}{n_1} \right)$$

Image that we observe is virtual image.



4 / 47

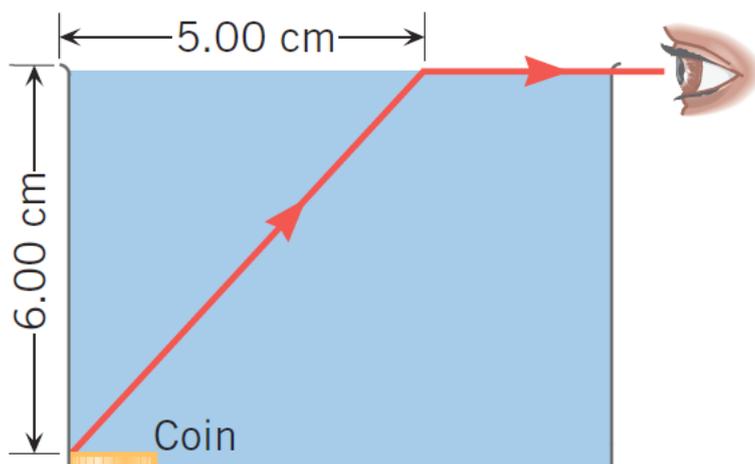
Problem 10

A layer of oil ($n = 1.45$) floats on an unknown liquid. A ray of light originates in the oil and passes into the unknown liquid. The angle of incidence is 64.0° , and the angle of refraction is 53.0° . What is the index of refraction of the unknown liquid?

5 / 47

Problem 13

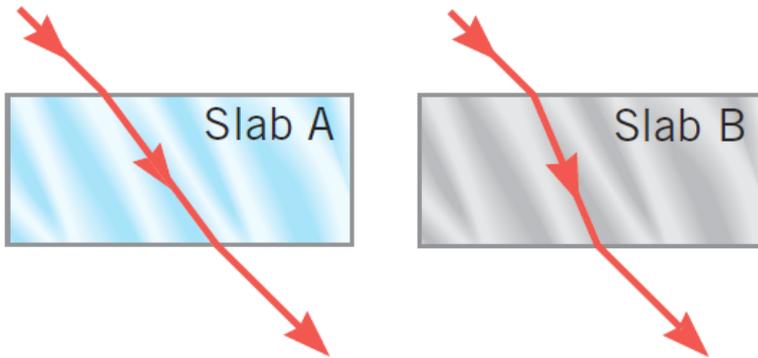
The drawing shows a coin resting on the bottom of a beaker filled with an unknown liquid. A ray of light from the coin travels to the surface of the liquid and is refracted as it enters into the air. A person sees the ray as it skims just above the surface of the liquid. How fast is the light traveling in the liquid?



6 / 47

Check Your Understanding 1

Two slabs with parallel faces are made from different types of glass. A ray of light travels through air and enters each slab at the same angle of incidence, as the drawing shows. Which slab has the greater index of refraction?

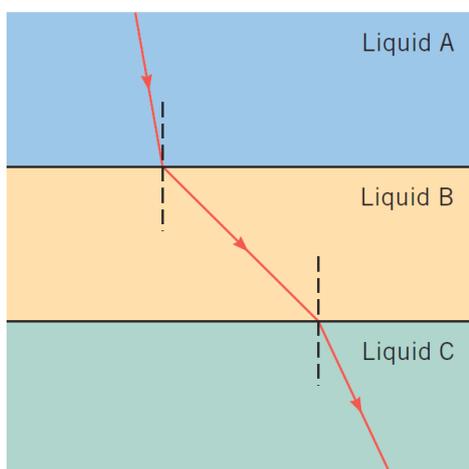


Question 1

7 / 47

Check Your Understanding 2

The drawing shows three layers of liquids, A, B, and C, each with a different index of refraction. Light begins in liquid A, passes into B, and eventually into C, as the ray of light in the drawing shows. The dashed lines denote the normals to the interfaces between the layers. Which liquid has the smallest index of refraction?



Question 2

8 / 47

Check Your Understanding 3

Light traveling through air is incident on a flat piece of glass at a 35° angle of incidence and enters the glass at an angle of refraction θ_{glass} . Suppose that a layer of water is added on top of the glass. Then the light travels through air and is incident on the water at the 35° angle of incidence. Does the light enter the glass at the same angle of refraction θ_{glass} as it did when the water was not present?

Check Your Understanding 4

Two identical containers, one filled with water ($n = 1.33$) and the other with benzene ($n = 1.50$) are viewed from directly above. Which container (if either) appears to have a greater depth of fluid?

9 / 47

Check Your Understanding 5

When an observer peers over the edge of a deep, empty, metal bowl on a kitchen table, he does not see the entire bottom surface. Therefore, a small object lying on the bottom is hidden from view, but the object can be seen when the bowl is filled with liquid A. When the bowl is filled with liquid B, however, the object remains hidden from view. Which liquid has the greater index of refraction?

Check Your Understanding 6

A man is fishing from a dock, using a bow and arrow. To strike a fish that he sees beneath the water, should he aim

- (a) somewhat above the fish,
- (b) directly at the fish,
- (c) somewhat below the fish?

10 / 47

Check Your Understanding 7

A man is fishing from a dock. He is using a laser gun that emits an intense beam of light. To strike a fish that he sees beneath the water, should he aim

- (a) somewhat above the fish,
- (b) directly at the fish,
- (c) somewhat below the fish?

Check Your Understanding 8

Two rays of light converge to a point on a screen. A thick plate of glass with parallel surfaces is placed in the path of this converging light, with the parallel surfaces parallel to the screen. Will the point of convergence

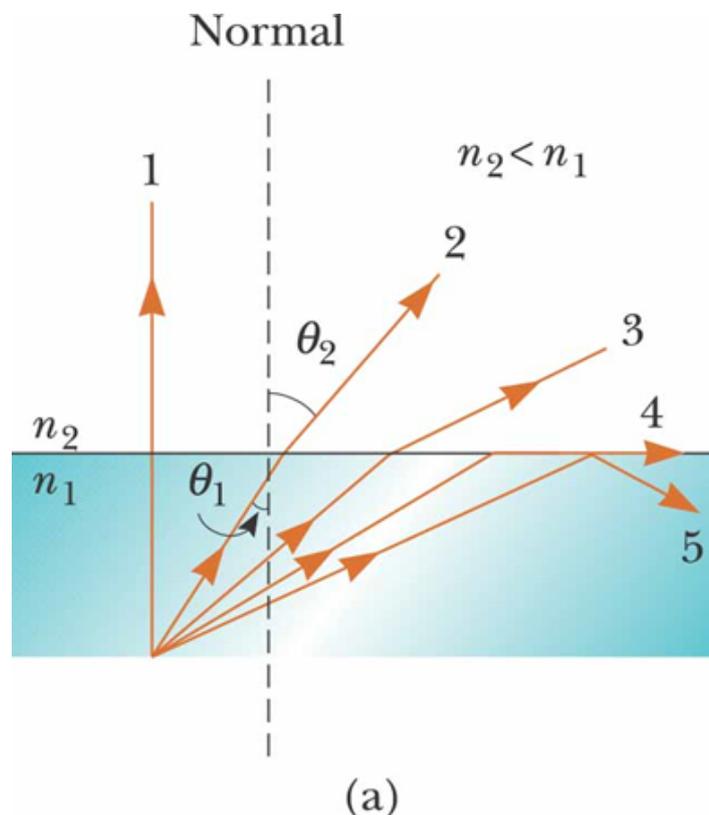
- (a) move away from the glass plate,
- (b) move toward the glass plate,
- (c) remain on the screen.

11 / 47

Total Internal Reflection

A phenomenon called total internal reflection can occur when light is directed from a medium having a given index of refraction **toward one having a lower index of refraction**.

This figure shows possible directions of the beam are indicated by rays numbered 1 through 5. The refracted rays are bent away from the normal since $n_1 > n_2$



12 / 47

Total Internal Reflection

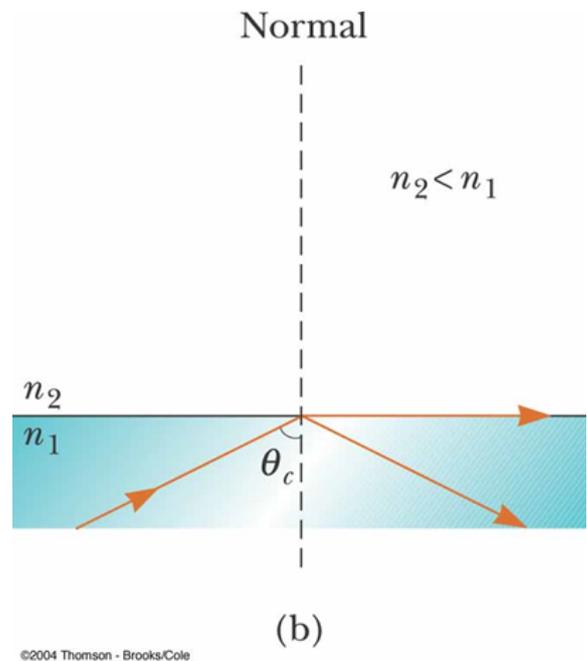
There is a particular angle of incidence that will result in an angle of refraction of 90° . This angle of incidence is called the critical angle, $\theta_{critical}$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n_1 \sin \theta_c = n_2 \sin 90$$

$$\theta_c = \sin^{-1} \left(\frac{n_2}{n_1} \right)$$

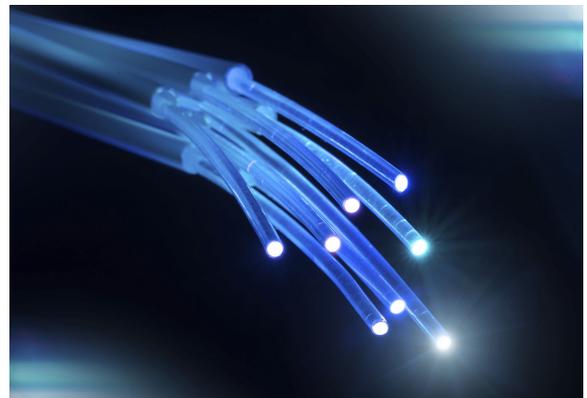
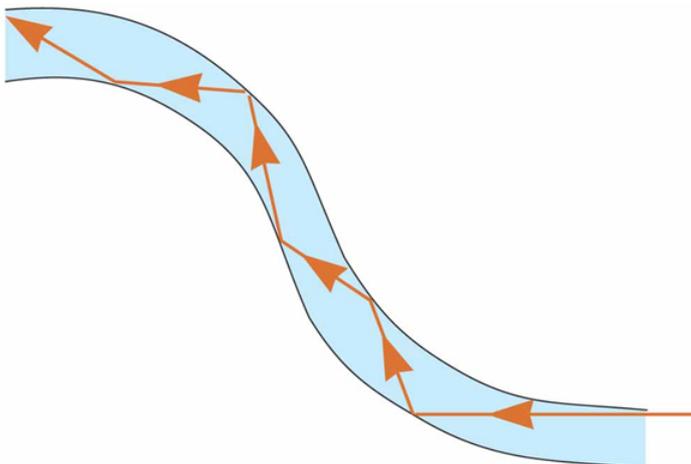
For angles of incidence greater than the critical angle, the beam is entirely reflected at the boundary



13 / 47

Total Internal Reflection: Fiber Optics

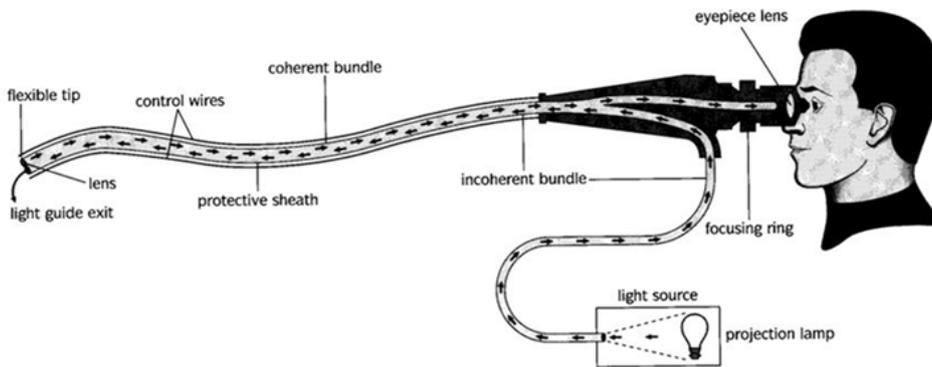
- An application of internal reflection
- Plastic or glass rods are used to “pipe” light from one place to another
- Applications include
 - ▶ Medical examination of internal organs
 - ▶ Telecommunications



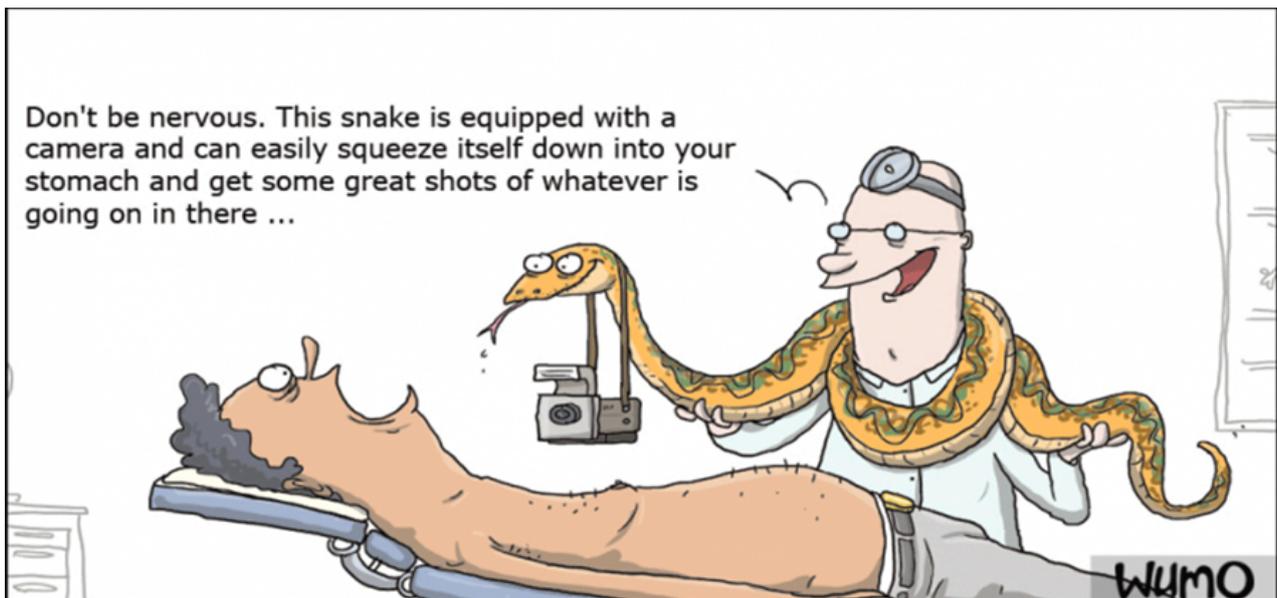


Total Internal Reflection: Fiber Optics-Endoscope.

An endoscopy uses total internal reflection to enable a doctor to look deep inside the body. It enables key hole surgery to take place



15 / 47



16 / 47

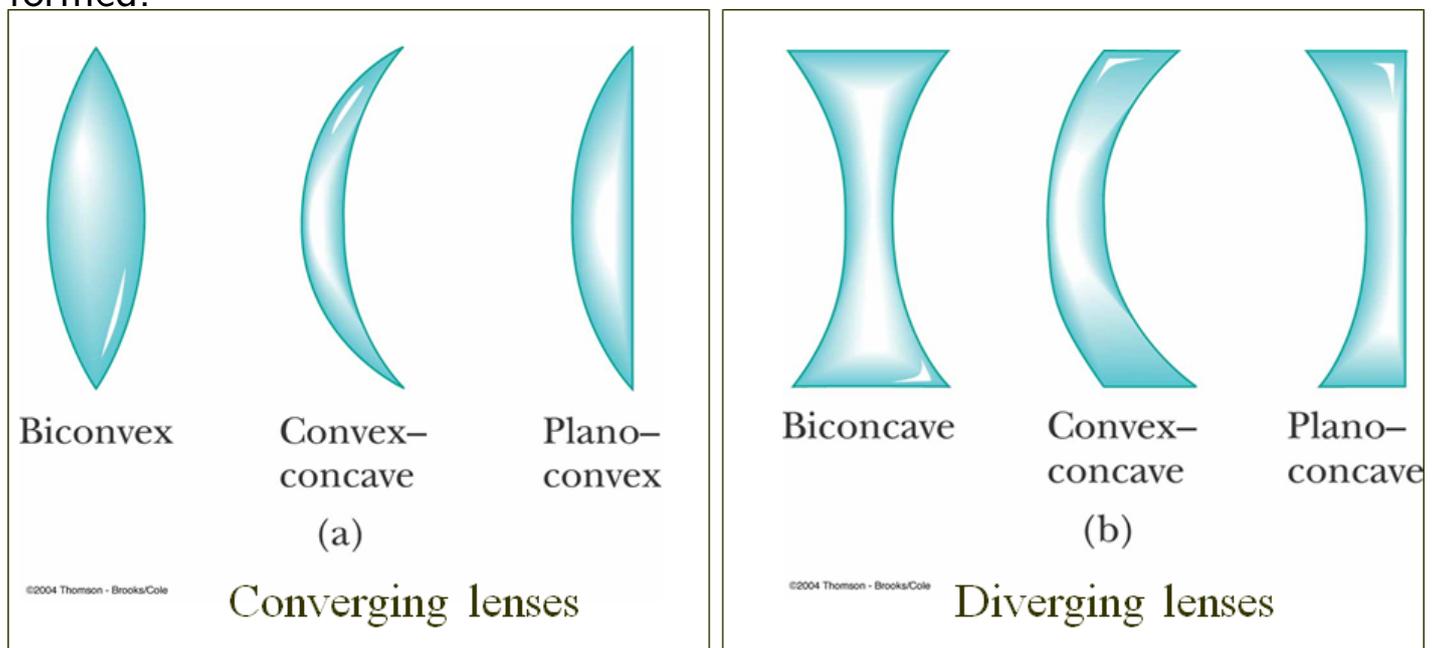
Problem 27

A glass is half-full of water, with a layer of vegetable oil ($n = 1.47$) floating on top. A ray of light traveling downward through the oil is incident on the water at an angle of 71.4° . Determine the critical angle for the oil–water interface and decide whether the ray will penetrate into the water.

17 / 47

Thin Lenses

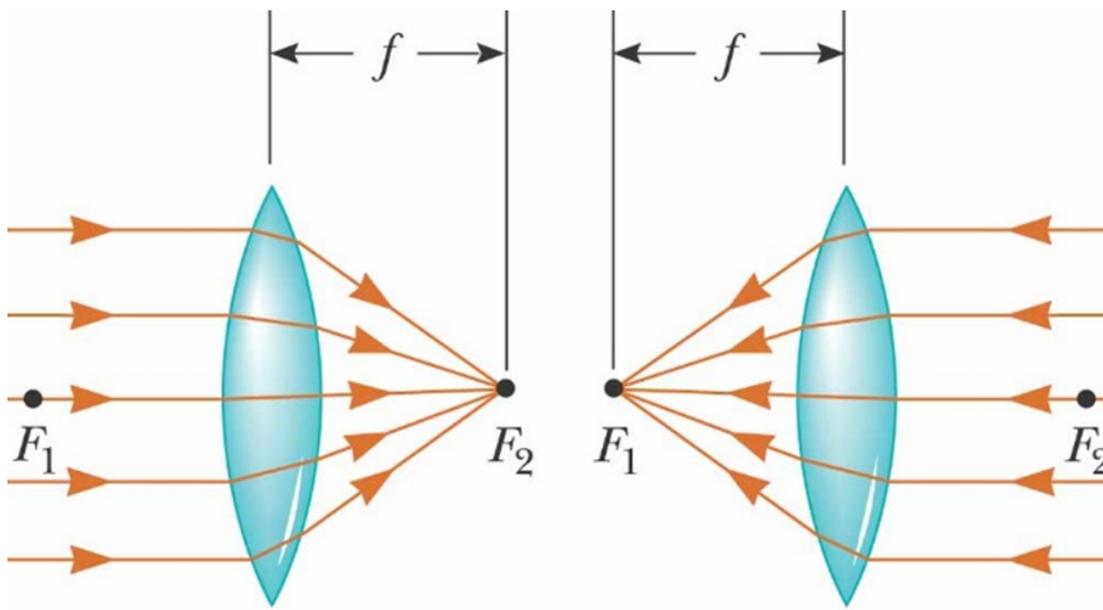
The lenses used in optical instruments, such as eyeglasses, cameras, and telescopes, are made from transparent materials that refract light. They refract the light in such a way that an image of the source of the light is formed.



18 / 47

Converging Lens

- The parallel rays pass through the lens and converge at the focal point
- The parallel rays can come from the left or right of the lens



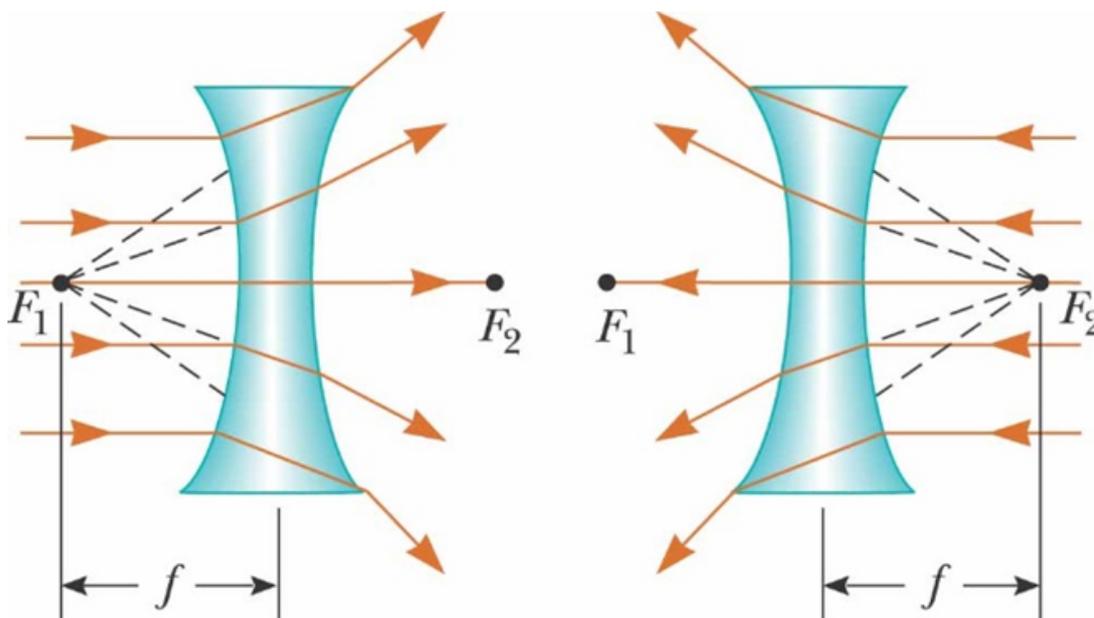
(a)

©2004 Thomson - Brooks/Cole

19 / 47

Diverging Lens

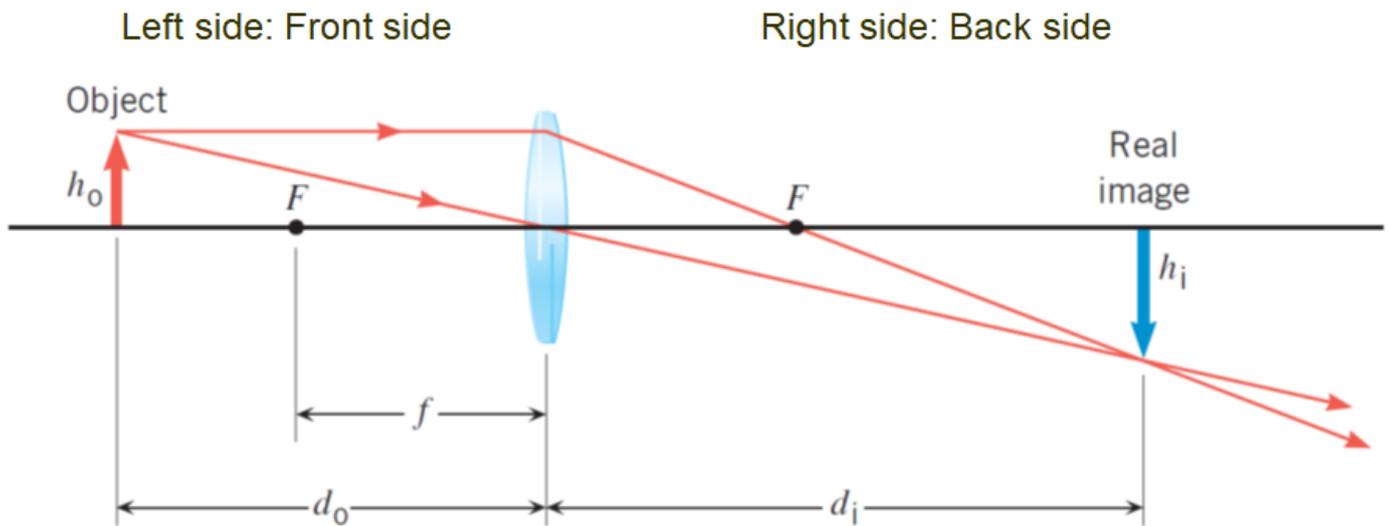
- The parallel rays diverge after passing through the diverging lens
- The focal point is the point where the rays appear to have originated



(b)

©2004 Thomson - Brooks/Cole

20 / 47

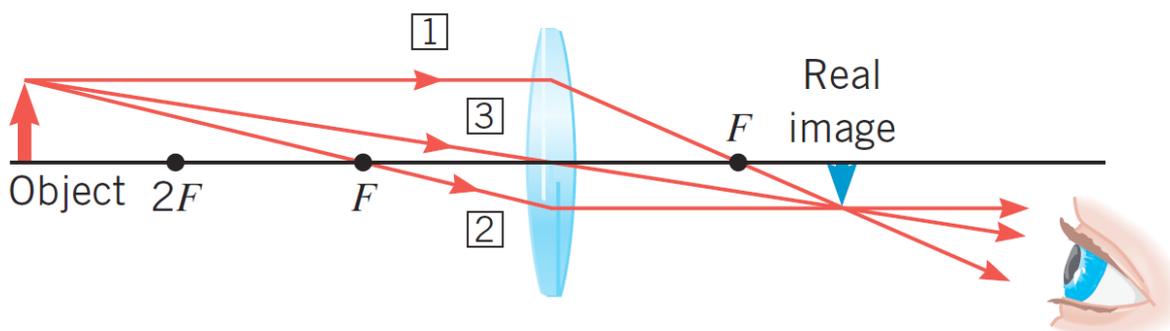


21 / 47

Ray Diagrams for Thin Lenses – Converging

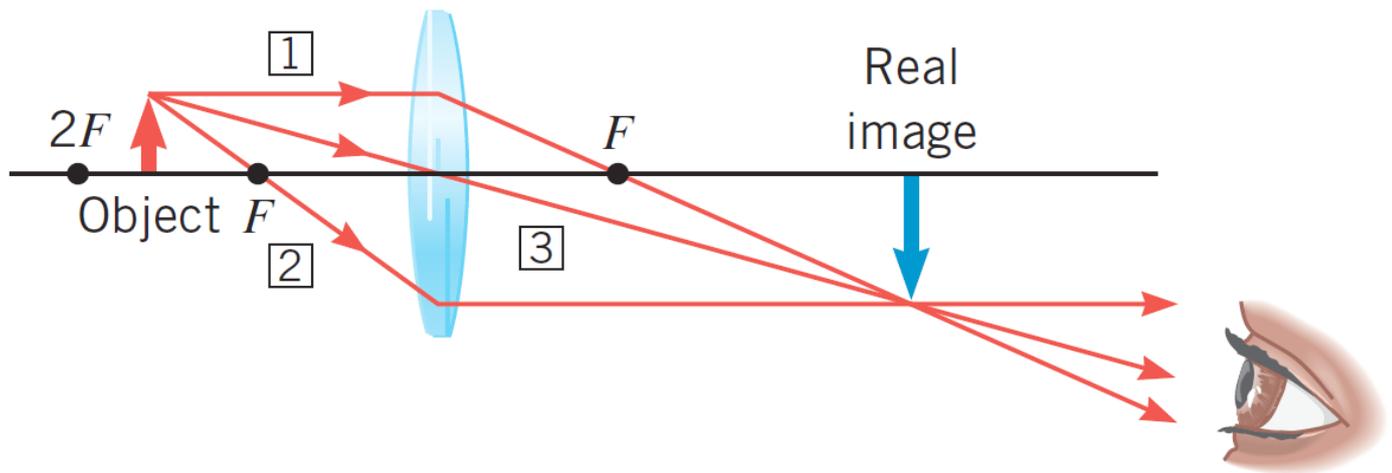
Ray diagrams are convenient for locating the images formed by thin lenses or systems of lenses. For a converging lens, the following three rays are drawn:

- Ray 1 is drawn parallel to the principal axis and then passes through the focal point on the back side of the lens
- Ray 2 is drawn through the center of the lens and continues in a straight line
- Ray 3 is drawn through the focal point on the front of the lens (or as if coming from the focal point if $d_o < f$) and emerges from the lens parallel to the principal axis



22 / 47

Ray Diagrams for Thin Lenses – Converging

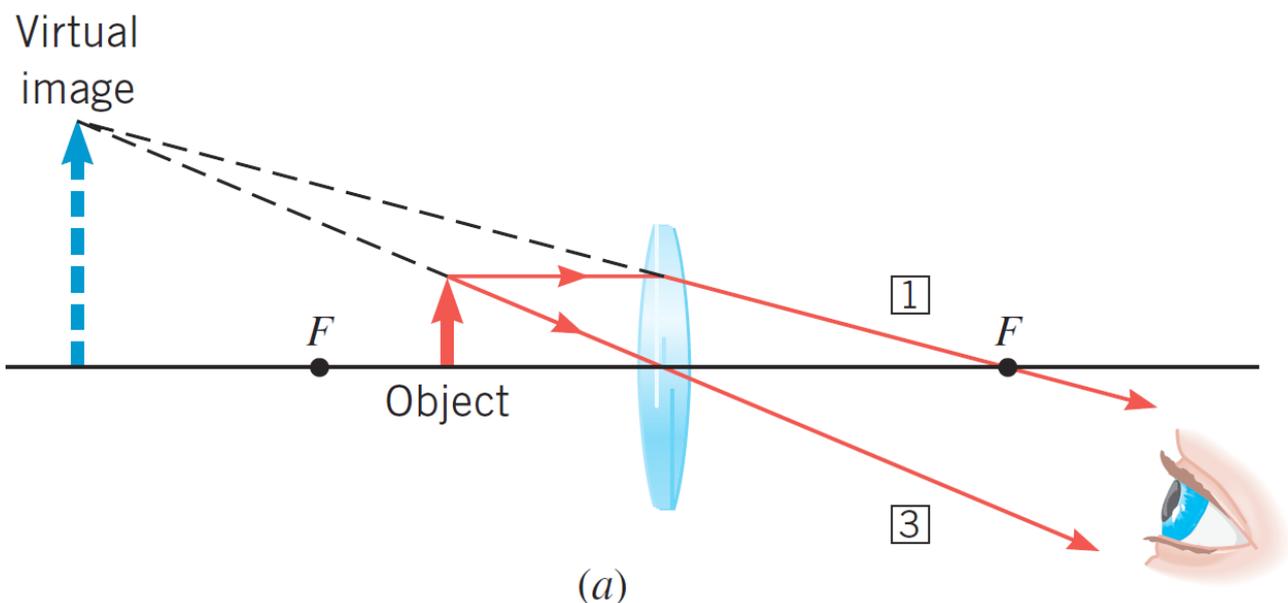


If $d_o > f$, the image characteristics:

- The image is real
- The image is inverted
- The image is on the back side of the lens

23 / 47

Ray Diagrams for Thin Lenses – Converging



If $d_o < f$, the image characteristics:

- The image is virtual
- The image is upright
- The image is larger than the object
- The image is on the front side of the lens

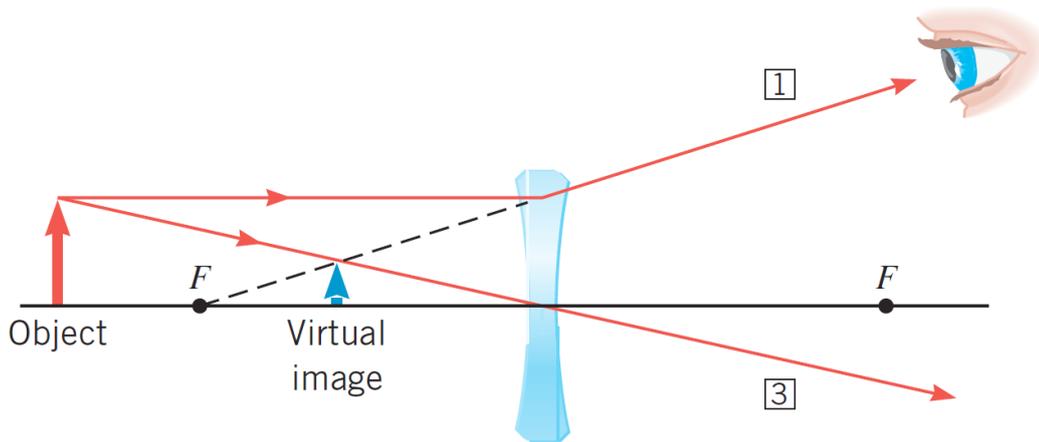
24 / 47

Ray Diagrams for Thin Lenses – Diverging

For a diverging lens, the following three rays are drawn:

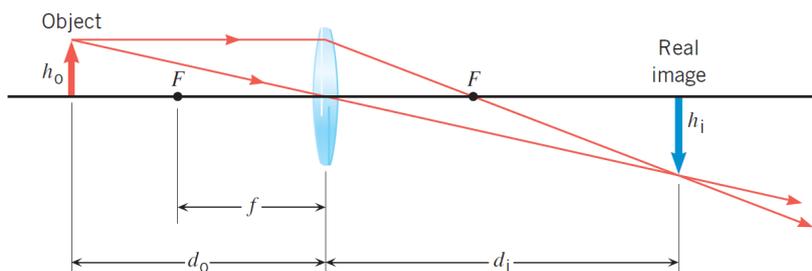
- Ray 1 is drawn parallel to the principal axis and emerges directed away from the focal point on the front side of the lens
- Ray 2 is drawn through the center of the lens and continues in a straight line
- Ray 3 is drawn in the direction toward the focal point on the back side of the lens and emerges from the lens parallel to the principal axis

For a diverging lens, the image is always virtual and upright. This is regardless of where the object is placed



25 / 47

Thin Lens Equation



Thin lens equation:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

The magnification:

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

For combinations of lenses:

$$m = m_1 m_2$$

Diopters:

Optometrists and ophthalmologists usually prescribe lenses measured in diopters. The power P of a lens in diopters equals the inverse of the focal length in meters $D = P = 1/f$

26 / 47

Summary of Sign Conventions for Lenses

Focal length

- f is + for a converging lens.
- f is - for a diverging lens.

Object distance

- d_o is + if the object is to the left of the lens (real object), as is usual.
- d_o is - if the object is to the right of the lens (virtual object)

Image distance

- d_i is + for an image (real) formed to the right of the lens by a real object.
- d_i is - for an image (virtual) formed to the left of the lens by a real object.

Magnification

- m is + for an image that is upright with respect to the object.
- m is - for an image that is inverted with respect to the object.

27 / 47

Check Your Understanding 15

A beacon in a lighthouse is to produce a parallel beam of light. The beacon consists of a light source and a converging lens. Should the light source be placed (a) between the focal point and the lens, (b) at the focal point of the lens, or (c) beyond the focal point? (Hint: Refer to Section 25.5 and review the principle of reversibility.)

Check Your Understanding 16

Review Conceptual Example 8 as an aid in answering this question. Is it possible for a lens to behave as a converging lens when surrounded by air but to behave as a diverging lens when surrounded by another medium?

28 / 47

Check Your Understanding 17

A converging lens is used to produce a real image, as in Figure 26.27a. A piece of black tape is then placed over the upper half of the lens. Which one of the following statements is true concerning the image that results with the tape in place? (a) The image is of the entire object, although its brightness is reduced since fewer rays produce it. (b) The image is of the object's lower half only, but its brightness is not reduced. (c) The image is of the object's upper half only, but its brightness is not reduced.

Check Your Understanding 18

A spherical mirror and a lens are immersed in water. Compared to the way they work in air, which one do you expect will be more affected by the water?

Check Your Understanding 19

An object is located at a distance d_o in front of a lens. The lens has a focal length f and produces an upright image that is twice as tall as the object. What kind of lens is it, and what is the object distance? Express your answer as a fraction or multiple of the focal length.

29 / 47

Problem 49

An object is located 9.0 cm in front of a converging lens ($f = 6.0\text{cm}$). Using an accurately drawn ray diagram, determine where the image is located.

Problem 57

A converging lens has a focal length of 88.00 cm. An object 13.0 cm tall is located 155.0 cm in front of this lens. (a) What is the image distance? (b) Is the image real or virtual? (c) What is the image height? Be sure to include the proper algebraic sign.

31 / 47

Problem 70

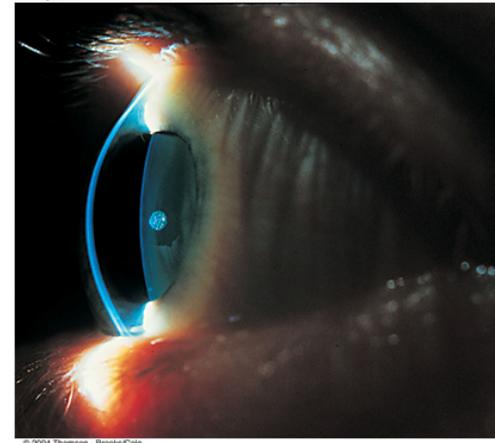
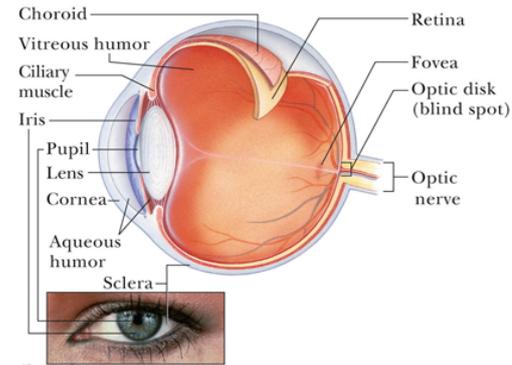
A diverging lens ($f = -10.0$ cm) is located 20.0 cm to the left of a converging lens ($f = 30.0$ cm). A 3.00-cm-tall object stands to the left of the diverging lens, exactly at its focal point. (a) Determine the distance of the final image relative to the converging lens. (b) What is the height of the final image (including the proper algebraic sign)?

32 / 47



The Human Eye.

- The eyeball is approximately spherical with a diameter of about 25 mm,
- Light enters the eye through a transparent membrane (the cornea),
- This membrane covers a clear liquid region (the aqueous humor),
- Behind which are a diaphragm (the iris) is the colored portion of the eye and controls the amount of light reaching the retina. The diameter of the pupil varies from about 2 to 7 mm,
- The lens, a region filled with a jelly-like substance (the vitreous humor),
- The retina. The retina is the light-sensitive part of the eye, consisting of millions, of structures called rods and cones. When stimulated by light, these structures send electrical, impulses via the optic nerve to the brain, which interprets the image detected by the retina.



33 / 47

The Eye: Accommodation

is the process by which the vertebrate eye changes optical power to maintain a clear image or focus on an object as its distance varies.

- The eye focuses on an object by varying the shape of the pliable crystalline lens through this process
- Takes place very quickly
- Limited in that objects very close to the eye produce blurred images

The near point:

The near point is the closest distance for which the lens can accommodate to focus light on the retina.

- Typically at age 10, this is about 18 cm
- The average value is about 25 cm
- It increases with age
- Up to 500 cm or greater at age 60

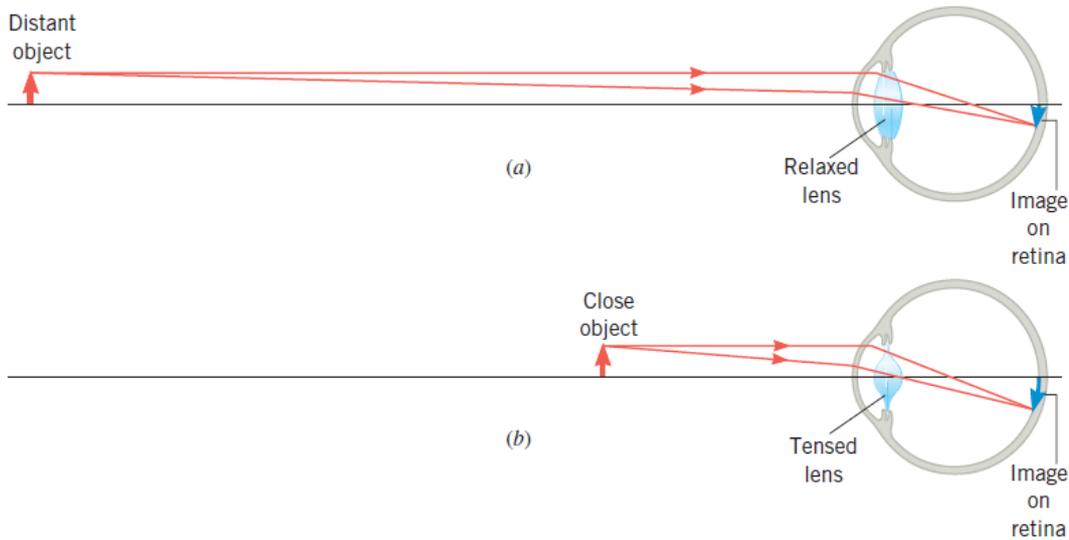
34 / 47

The Eye: Accommodation

The far point:

The far point of the eye represents the largest distance for which the lens of the relaxed eye can focus light on the retina

Normal vision has a far point of infinity



35 / 47

Eye Disorders

Eyes may suffer a mismatch between the focusing power of the lens-cornea system and the length of the eye

Farsighted

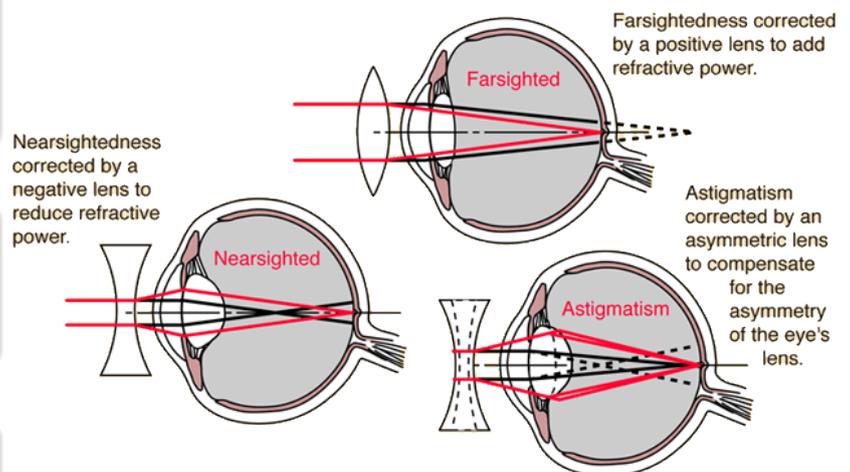
Light rays reach the retina before they converge to form an image

Nearsighted

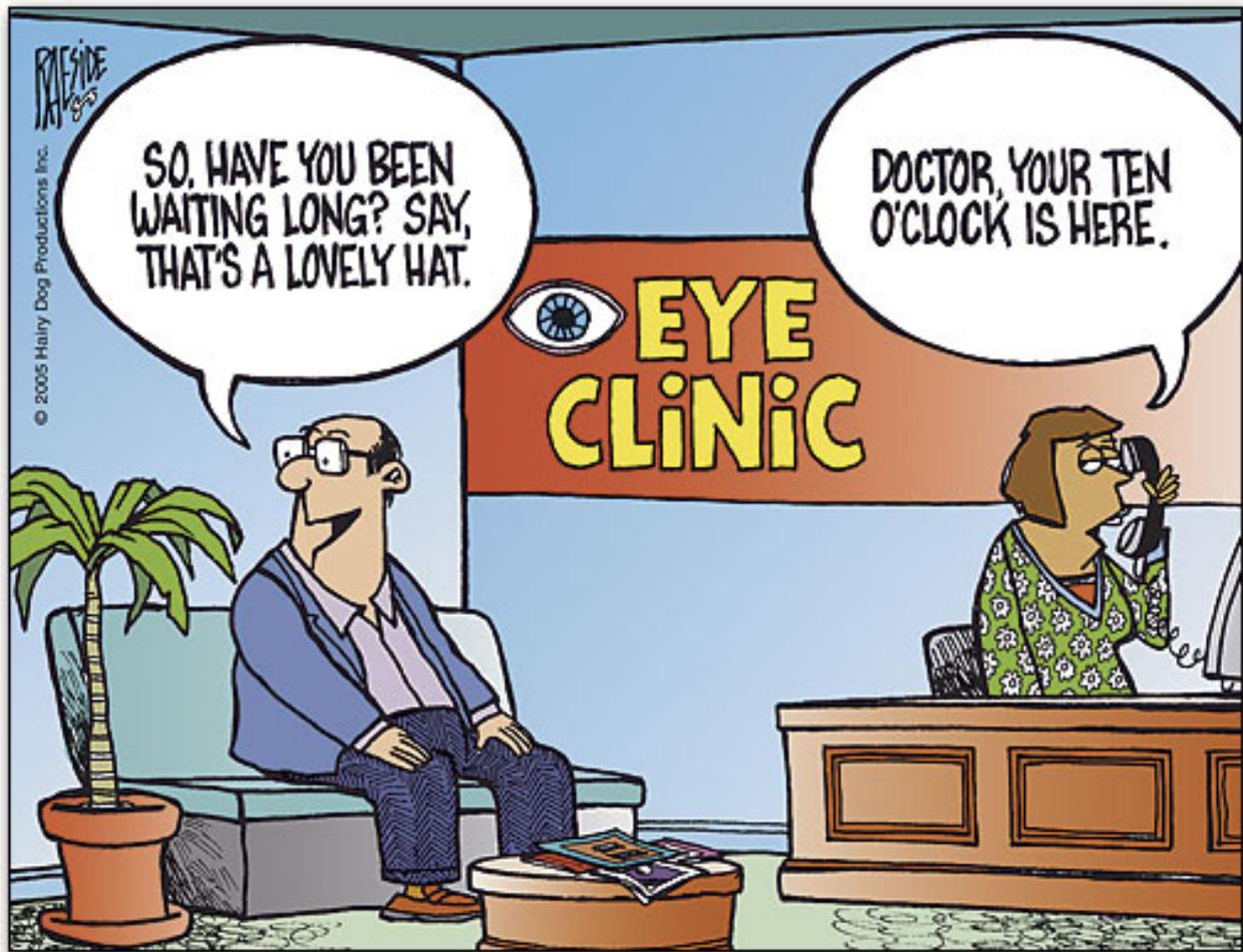
Person can focus on nearby objects but not those far away

Astigmatism

Causes blurred vision. It occurs when the cornea is irregularly shaped or sometimes because of the curvature of the lens inside the eye.



36 / 47



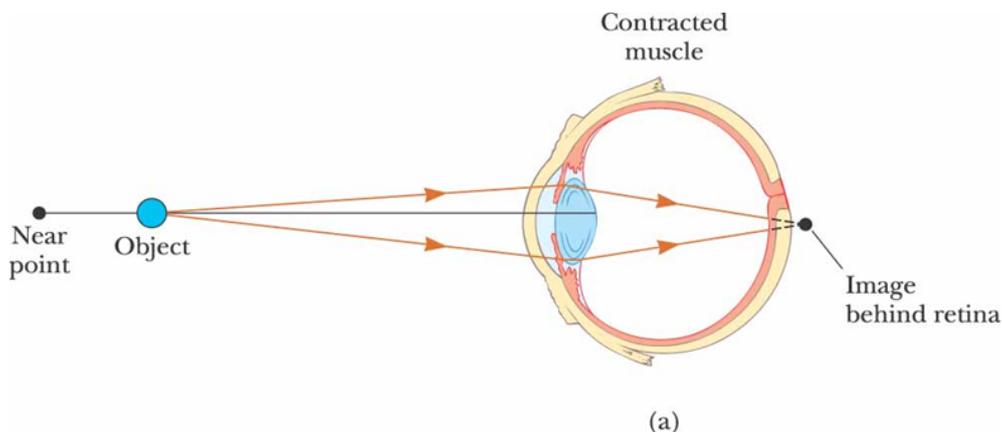
37 / 47



Farsightedness.

Also called hyperopia

- The near point of the farsighted person is much farther away than that of the normal eye
- The image focuses behind the retina
- Can usually see far away objects clearly, but not nearby objects

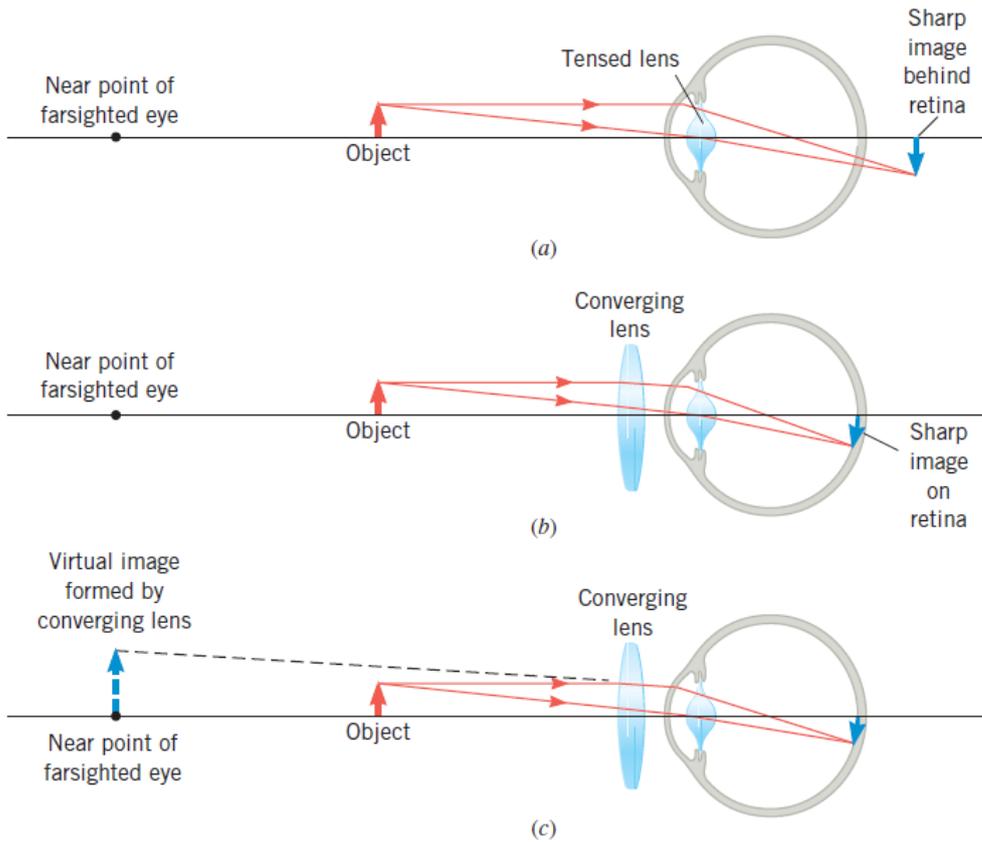


©2004 Thomson - Brooks/Cole

38 / 47



Farsightedness: Correction.



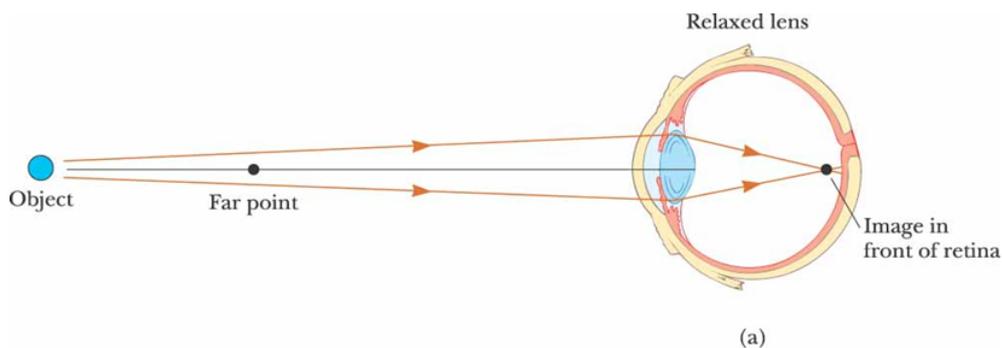
(a) When a farsighted person views an object located between the near point and the eye, a sharp image would be formed behind the retina if light could pass through it. Only a blurred image forms on the retina. (b) With a converging lens in front of the eye, the sharp image is moved onto the retina and clear vision results. (c) The converging lens is designed to form a virtual image at the near point of the farsighted eye.



Nearsightedness.

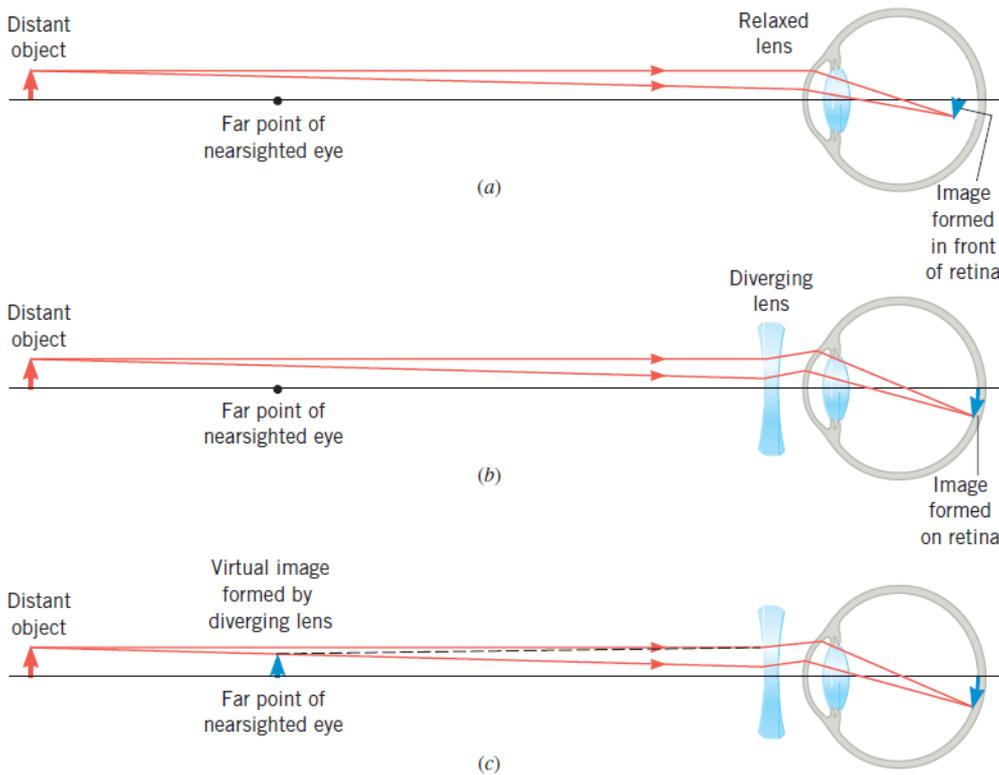
Also called myopia

- The far point of the nearsighted person is not infinity and may be less than one meter
- The nearsighted person can focus on nearby objects but not those far away
- Cant usually see far away objects clearly.





Nearsightedness: Correction.



(a) When a nearsighted person views a distant object, the image is formed in front of the retina. The result is blurred vision. (b) With a diverging lens in front of the eye, the image is moved onto the retina and clear vision results. (c) The diverging lens is designed to form a virtual image at the far point of the nearsighted eye.

Check Your Understanding 21

Two people who wear glasses are camping. One is nearsighted, and the other is farsighted. Whose glasses may be useful in starting a fire by concentrating the sun's rays into a small region at the focal point of the lens used in the glasses?

Check Your Understanding 22

Suppose that a person with a near point of 26 cm is standing in front of a plane mirror. How close can he stand to the mirror and still see himself in focus?

Check Your Understanding 23

To a swimmer under water, objects look blurred. However, goggles that keep the water away from the eyes allow the swimmer to see objects in sharp focus. Why?

Check Your Understanding 24

When glasses use diverging lenses to correct for nearsightedness or converging lenses to correct for farsightedness, the eyes of the person wearing the glasses lie between the lenses and their focal points. When you look at the eyes of this person, they do not appear to have their normal size. Which one of the following describes what you see? (a) The converging lenses make the eyes appear smaller, and the diverging lenses make the eyes appear larger. (b) The converging lenses make the eyes appear larger, and the diverging lenses make the eyes appear smaller. (c) Both types of lenses make the eyes appear larger. (d) Both types of lenses make the eyes appear smaller.

43 / 47

Example: Eyeglasses for the Nearsighted Person

A nearsighted person has a far point located only 521 cm from the eye. Assuming that eyeglasses are to be worn 2 cm in front of the eye, find the focal length needed for the diverging lenses of the glasses so the person can see distant objects.

44 / 47

Example: Contact Lenses for the Farsighted Person

A farsighted person has a near point located 210 cm from the eyes. Obtain the focal length of the converging lenses in a pair of contacts that can be used to read a book held 25.0 cm from the eyes.

45 / 47

Problem 76

A woman can read the large print in a newspaper only when it is at a distance of 65 cm or more from her eyes. (a) Is she nearsighted (myopic) or farsighted (hyperopic), and what kind of lens is used in her glasses to correct her eyesight? (b) What should be the refractive power (in diopters) of her glasses (worn 2.0 cm from the eyes), so she can read the newspaper at a distance of 25 cm from the eyes?

46 / 47

Homework Problems: Homework: 6, 11, 15, 28, 50, 52

The End

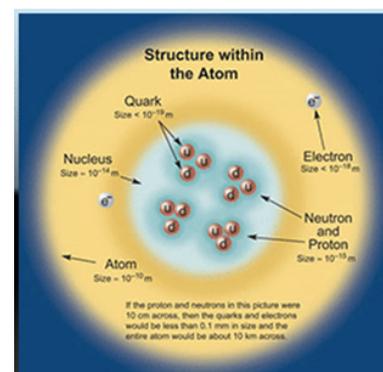
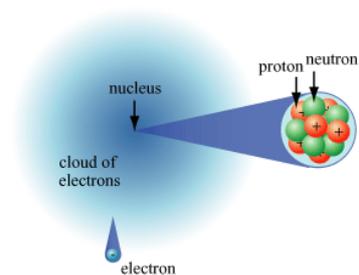
The Nature of the Atom (Chapter 30)

- 1 Modern Atom Model.
- 2 Line Spectra
- 3 Quantum Mechanical Model
- 4 X-rays
- 5 Interaction of X-rays with Matter
- 6 The Physics of CAT Scanning
- 7 Laser
- 8 Medical Applications of the Laser
 - The Physics of PRK Eye Surgery.
- 9 Medical Applications of the Laser
 - Lasik versus PRK Eye Surgery.
 - The Physics of LASIK Eye Surgery.
 - The Physics of Photo-dynamic Therapy for Cancer.
 - The Physics of Removing Port-Wine Stains.

1 / 55

Modern Atom Model.

- The current model of the atom shows an atom that is mostly empty space.
- In the center is a small nucleus made of protons and neutrons.
- protons and neutrons jiggle within the nucleus, and quarks jiggle within the protons and neutrons.
- The nucleus contains nearly all the mass of an atom.
- Surrounding the nucleus is a cloud-like region with electrons moving too fast and too unpredictably for us to know their location.
- This model continues to be refined as new technology is developed that allows us to better observe atoms and their behavior.

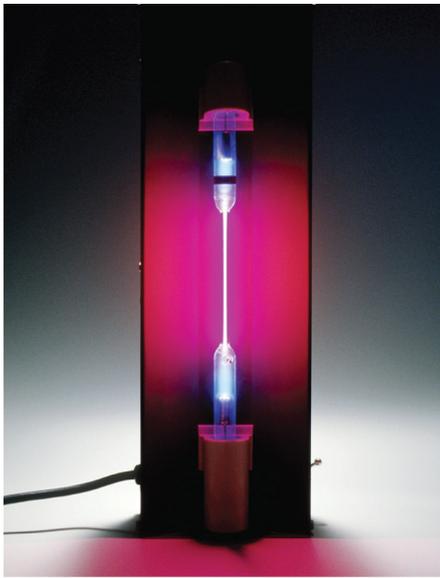


2 / 55

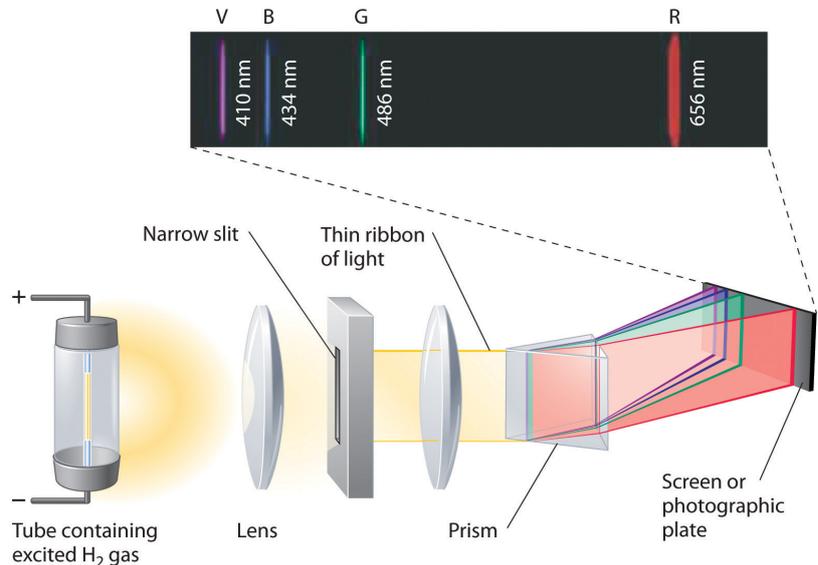
Line Spectra

Line Spectrum: series of fringes produced when low-pressure gas in sealed tube made to emit EM waves via large potential difference Lyman, Balmer, and Paschen Series.

The emission and absorption spectra of the elements depend on the electronic structure of the atom.



(a)



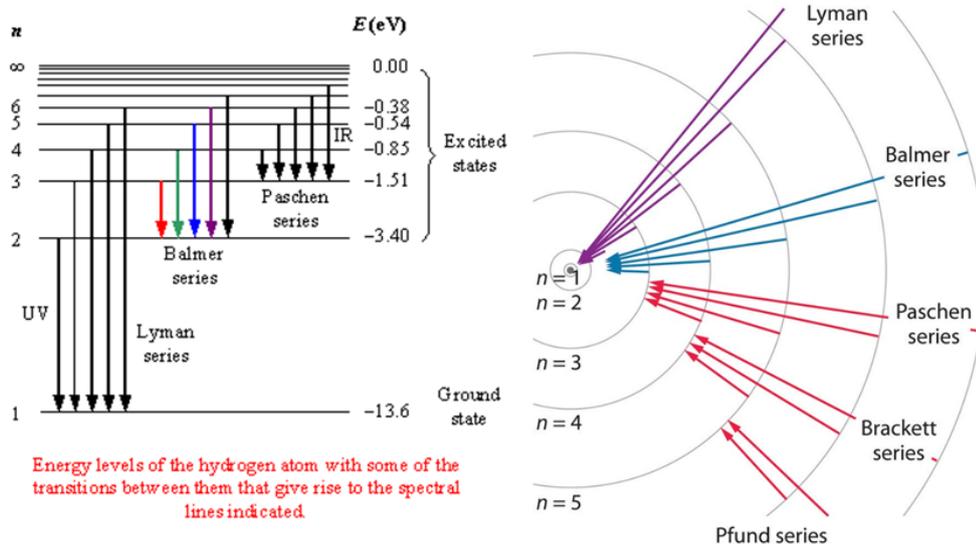
(b)

Line Spectra

The emission spectrum of atomic hydrogen is divided into a number of spectral series, with wavelengths given by the Rydberg formula. These observed spectral lines are due to the electron making transitions between two energy levels in an atom.

$$\frac{1}{\lambda} = R \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

R is the Rydberg constant: $R = 1.097 \times 10^7 \text{ m}^{-1}$



Energy levels of the hydrogen atom with some of the transitions between them that give rise to the spectral lines indicated.

Example: The Balmer Series

Find (a) the longest and (b) the shortest wavelengths of the Balmer series.

5 / 55

Problem 13

A hydrogen atom is in the ground state. It absorbs energy and makes a transition to the $n = 3$ excited state. The atom returns to the ground state by emitting two photons. What are their wavelengths?

6 / 55

Quantum Mechanical Model: Key Points

- Louis de Broglie proposed that all particles could be treated as matter waves with a wavelength λ , given by the following equation: $\lambda = \frac{h}{mv}$
- Erwin Schrödinger proposed the quantum mechanical model of the atom, which treats electrons as matter waves.
- Schrödinger's equation, can be solved to yield a series of wave function ψ , each of which is associated with an electron binding energy, E .
- The square of the wave function, $|\psi|^2$, represents the probability of finding an electron in a given region within the atom.
- An atomic orbital is defined as the region within an atom that encloses where the electron is likely to be 90% of the time.
- The Heisenberg uncertainty principle states that we can't know both the energy and position of an electron. Therefore, as we learn more about the electron's position, we know less about its energy, and vice versa.
- Electrons have an intrinsic property called spin, and an electron can have one of two possible spin values: spin-up or spin-down.
- Any two electrons occupying the same orbital must have opposite spins.

7 / 55

Introduction to Quantum Numbers

Each electron in an atom is described by four different quantum numbers. The first three (n, ℓ, m_ℓ) specify the particular orbital of interest, and the fourth (m_s) specifies how many electrons can occupy that orbital.

1. **Principal Quantum Number (n):** $n = 1, 2, 3, \dots$. Specifies the energy of an electron and the size of the orbital.

- All orbitals that have the same value of n are said to be in the same shell (level).
- For a hydrogen atom with $n=1$, the electron is in its ground state; if the electron is in the $n=2$ orbital, it is in an excited state.
- The total number of orbitals for a given n value is n^2 .

8 / 55

Introduction to Quantum Numbers

Angular Momentum l : $l = 0, \dots, n-1$.

- Specifies the shape of an orbital with a particular principal quantum number n .
- The secondary quantum number divides the shells into smaller groups of orbitals called subshells (sublevels).
 - Usually, a letter code is used to identify l to avoid confusion

l	0	1	2	3	4	5
Letter	s	p	d	f	g	h

- The value of l also has a slight effect on the energy of the subshell; the energy of the subshell increases with l

9 / 55

Introduction to Quantum Numbers

Magnetic Quantum Number (m_l): $m_l = -l, \dots, 0, \dots, +l$. Specifies the orientation in space of an orbital of a given energy (n) and shape (l). This number divides the subshell into individual orbitals which hold the electrons; there are $2l + 1$ orbitals in each subshell. Thus the s subshell has only one orbital, the p subshell has three orbitals, and so on.

10 / 55

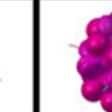
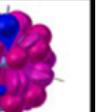
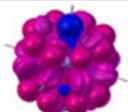
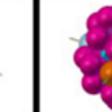
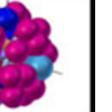
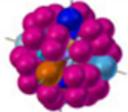
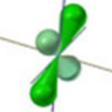
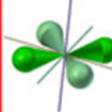
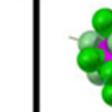
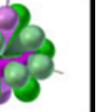
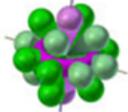
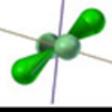
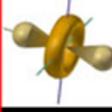
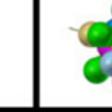
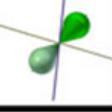
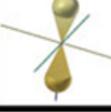
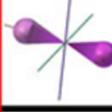
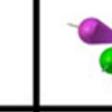
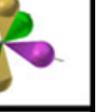
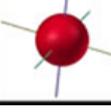
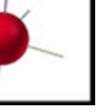
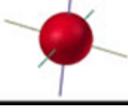
Introduction to Quantum Numbers

Spin Quantum Number (m_s): This number is needed because the electron has an intrinsic property called “spin angular momentum.” Loosely speaking, we can view the electron as spinning while it orbits the nucleus, analogous to the way the earth spins as it orbits the sun. There are two possible values for the spin quantum number of the electron:

$$m_s = \pm \frac{1}{2}$$

Sometimes the phrases “spin up” and “spin down” are used to refer to the directions of the spin angular momentum associated with the values for m_s

11 / 55

THE spdf ORBITALS (An artistic rendition)				Joel M Williams ©2013 JW 11=11							
TYPE	SET	INDIVIDUAL ORBITALS			COLLECTIVE						
f	Cubic										
	General										
d	Common										
	“Tri-torus”										
p											
s											

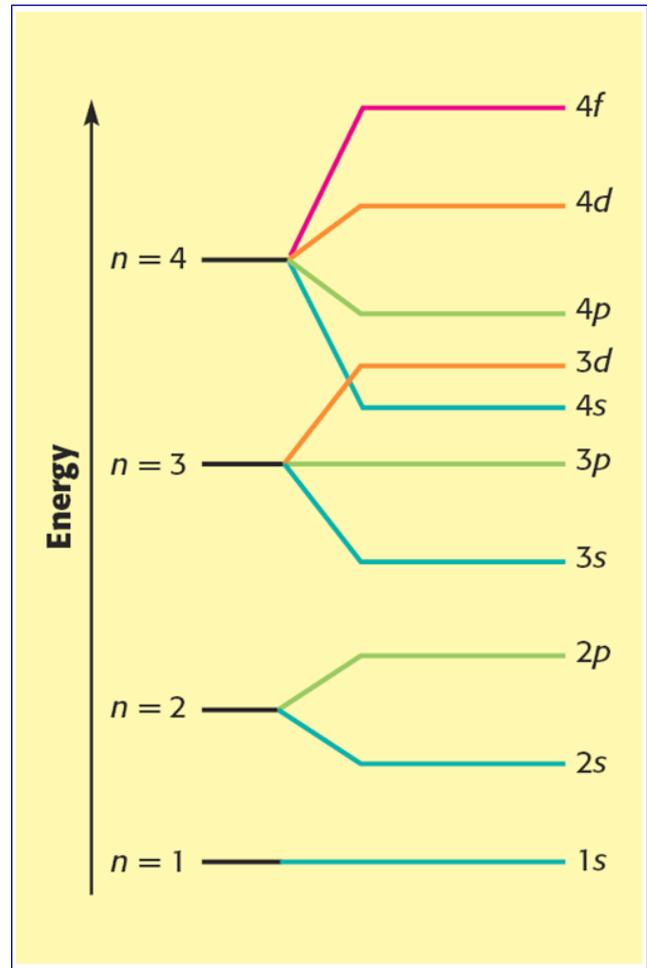
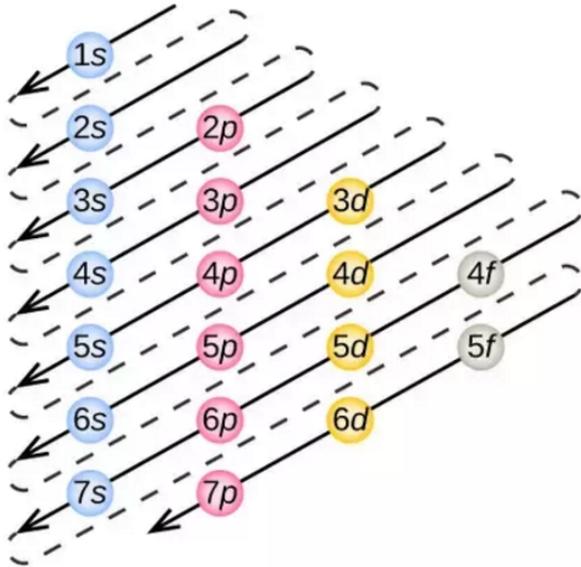
12 / 55

Electronic Configuration

This diagrams shows how the energy of the orbitals can overlap.

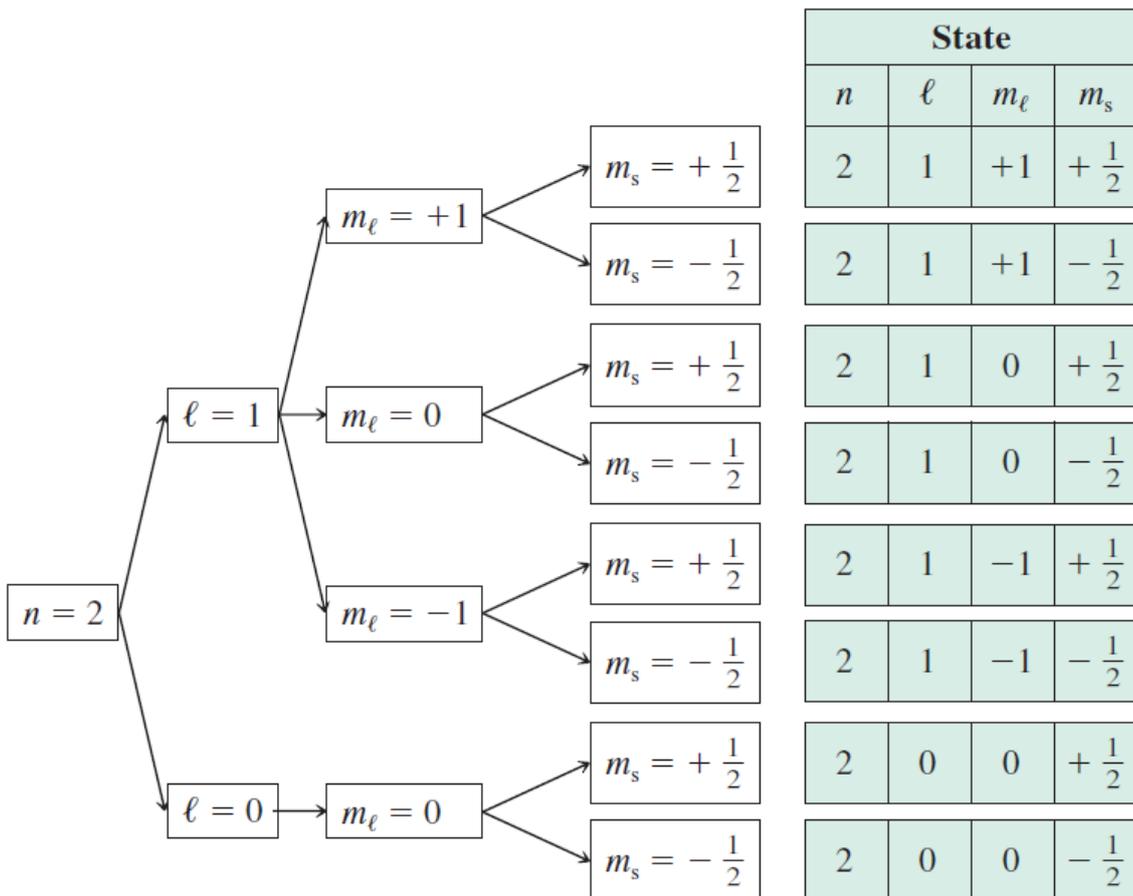
$$1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p < 5s < 4d$$

$$3d < 4p < 5s < 4d$$



13 / 55

List of quantum numbers for the shell $n=2$



14 / 55

Problem 24

The table lists quantum numbers for five states of the hydrogen atom. Which (if any) of them are not possible? For those that are not possible, explain why.

	n	ℓ	m_ℓ
(a)	3	3	0
(b)	2	1	-1
(c)	4	2	3
(d)	5	-3	2
(e)	4	0	0

15 / 55

Problem 25

The orbital quantum number for the electron in a hydrogen atom is $\ell = 5$. What is the smallest possible value (the most negative) for the total energy of this electron? Give your answer in electron volts.

16 / 55

X-rays

X-rays were discovered by the Dutch physicist Wilhelm K. Roentgen (1845–1923), who performed much of his work in Germany.

X-ray photons are created by the interaction of energetic electrons or particles with matter at the atomic level. Photons (x-ray and gamma) end their lives by transferring their energy to electrons contained in matter.

X-ray interactions are important in diagnostic examinations. For example, the selective interaction of x-ray photons with the structure of the human body produces the image that can be viewed or recorded.



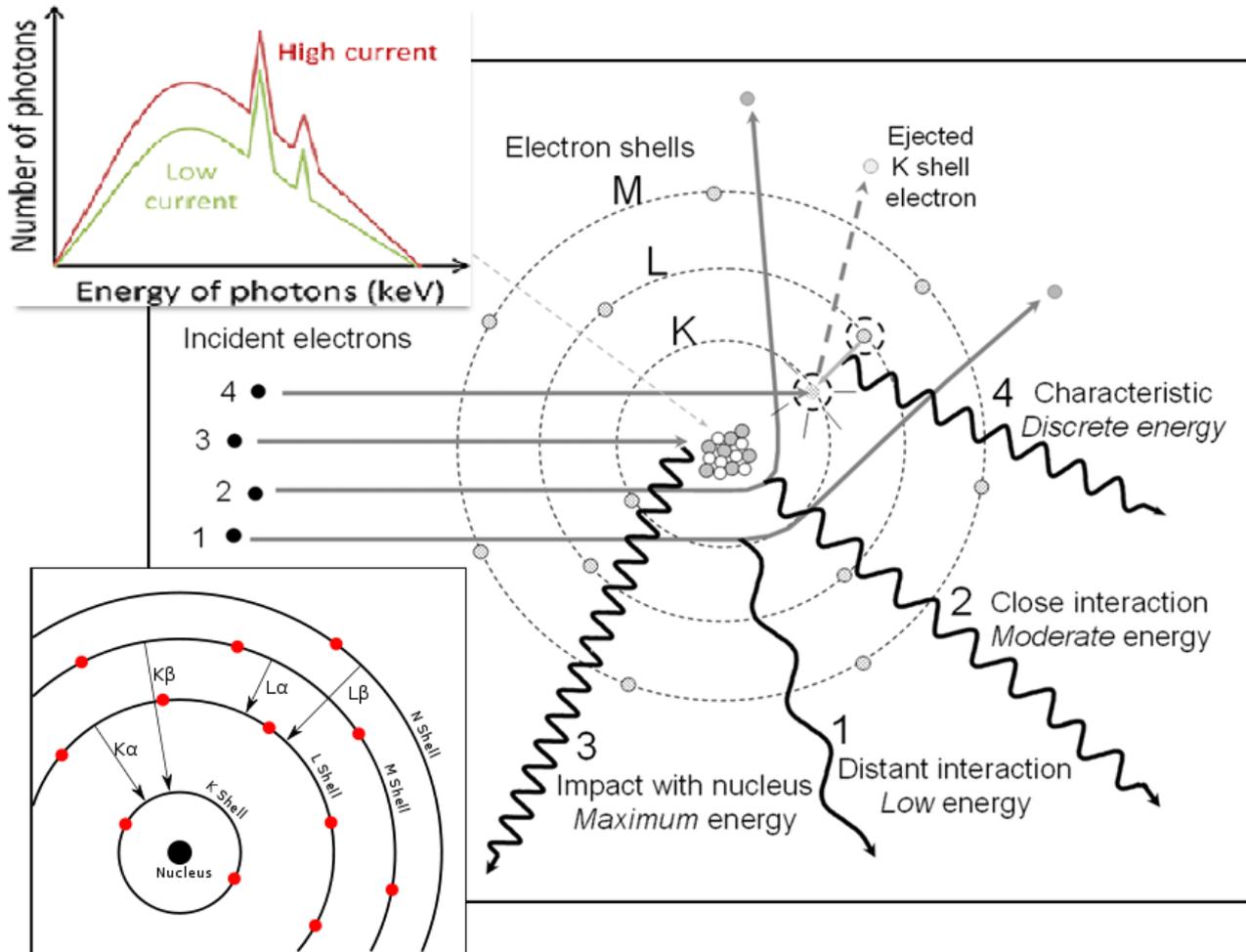
17 / 55

X-rays

- X-ray can penetrate liquids, gas and solids.
- The point of penetration is based on the intensity, quality and wavelength of the X-ray beams.
- X-ray imaging based on the absorption of low level radiation by parts of our body with higher density, making the radiation not absorbed hit the photographic 'plate' to form a 'negative image'. This means the waves of X-ray can penetrate through materials of light atoms, such as flesh, that is why flesh is not seen during imaging with X-rays.
- Bones, which are heavier atoms than flesh (due to the calcium in them), absorb the X-rays. The absorbed X-rays by the bones then glow on the photographic film.
- Meaning the higher the density of the material the brighter it will be imaged on the photographic film.

18 / 55

X-ray Spectra



19 / 55

X-ray Spectra

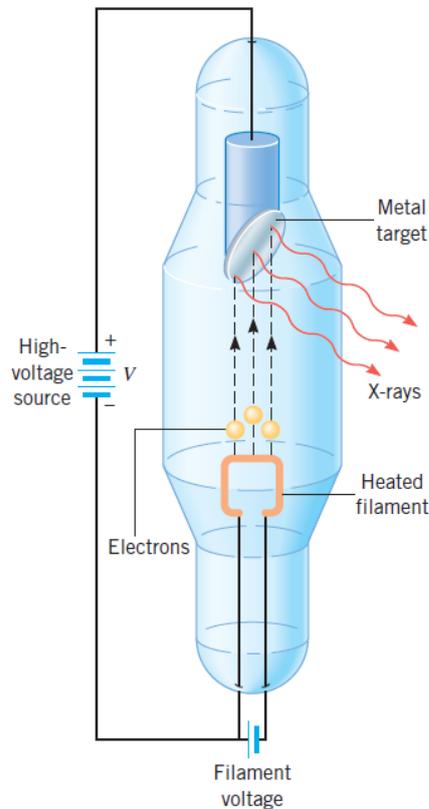
- X-rays are a result of the slowing down of high energy electrons as they strike a metal target
- The kinetic energy lost can be anywhere from 0 to all of the kinetic energy of the electron
- The continuous spectrum is called bremsstrahlung, the German word for “braking radiation”
- The discrete lines are called characteristic x-rays. These are created when
 - ▶ A bombarding electron collides with a target atom
 - ▶ The electron removes an inner-shell electron from orbit
 - ▶ An electron from a higher orbit drops down to fill the vacancy

When generating X-rays by X-ray tube: out of a 100% energy consumed, there is: 99% Heat, 0.85% Continuous spectrum, and 0.15% Characteristic radiation

20 / 55

Generating X-ray by X-ray Tube

An x-ray tube is an energy converter. It receives electrical energy and converts it into two other forms: x-radiation and heat.



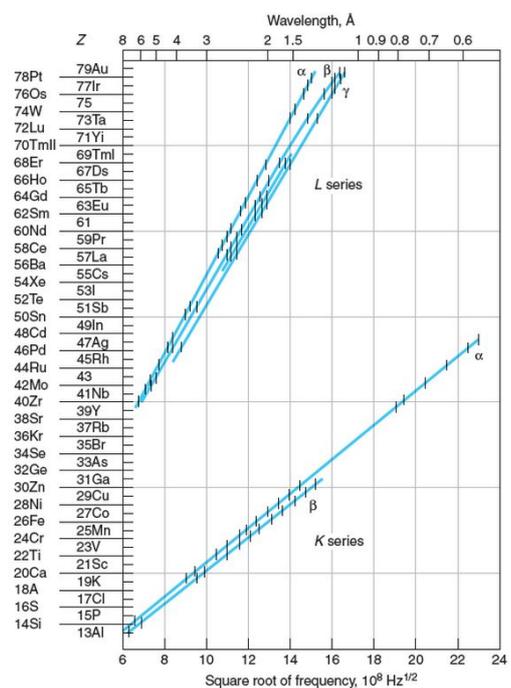
21 / 55

X-rays: Moseley Plot of Characteristic X-rays

- When the square root of the frequencies of the characteristic x-rays from the elements is plotted against the atomic number, a straight line is obtained.
- Moseley showed that the K-alpha x-rays followed a straight line when the atomic number Z versus the square root of frequency was plotted.
- With the insights gained from the Bohr model, we can write his empirical relationship as follows:

$$E_{K\alpha} = 13.6 (Z - 1)^2 \left[\frac{1}{1^2} - \frac{1}{2^2} \right]$$

$$E_{K\alpha} = \frac{3}{4} 13.6 (Z - 1)^2 \text{ eV}$$



22 / 55

Example: X-ray Spectra

Use Moseley equation (Bohr model) to estimate the wavelength of the K_α line in the X-ray spectrum of platinum ($Z = 78$).

23 / 55

Example: X-ray Spectra

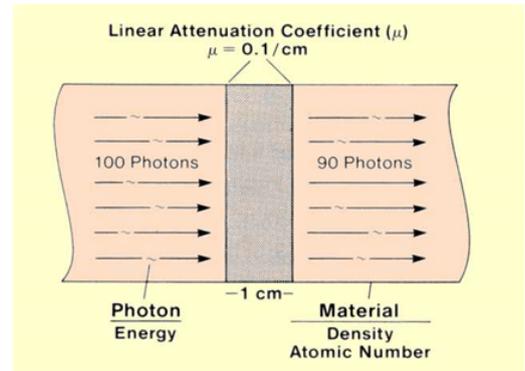
When a certain element is bombarded with high-energy electrons, K_α X-rays that have an energy of 9890 eV are emitted. Determine the atomic number Z of the element, and identify the element. Use the Bohr model as necessary.

24 / 55

Interaction of X-rays with Matter

Let us observe what happens when a group of photons encounters a slice of material that is 1 cm thick and has $\mu = 0.1 \text{ cm}^{-1}$

- Some of the photons interact with the material
- Some pass on through.
- The interactions, either photoelectric or Compton, remove some of the photons from the beam in a process known as attenuation.
- Under specific conditions, a certain percentage of the photons will interact, or be attenuated, in a 1-cm thickness of material.



$$I = I_0 e^{-\mu x}$$

$$I = I_0 e^{-\mu x}$$

$$I = 100 e^{-1} = 90$$

Where: I : is the transmitted intensity, I_0 : is the initial intensity μ : is the linear absorption coefficient x : is the distance

25 / 55

Attenuations of x-rays

Linear Attenuation Coefficients (cm^{-1})	Conversion To CT Units	Hounsfield Units
Bone 0.528	$\frac{\mu_t - \mu_w}{\mu_w} \times k = \text{HU}$	Bone 1000
Muscle 0.237		Muscle 50
Brain White 0.213		Brain White 45
Brain Gray 0.212		Brain Gray 40
Blood 0.208		Blood 20
Water 0.206		Water 0
Fat 0.185		Fat -100
Lung 0.093		Lung -200
Air 0.0004		Air -1000

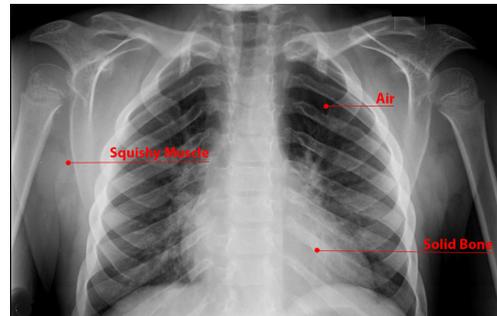
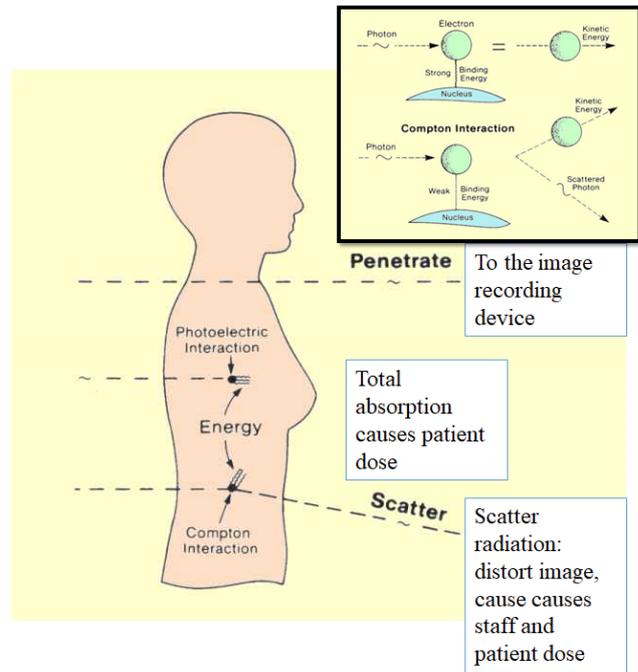
26 / 55



X-rays: image formation.

Interaction of x-rays with human body

- **No interaction:** x-ray passes completely through tissue and into the image recording device
- **Complete absorption:** x-ray energy is completely absorbed by the tissue. No imaging information results
- **Partial absorption with scattering:** scattering involves partial transfer energy to tissue, with the resulting scattered x-ray having less energy and different trajectory. Scattered radiation tend to **degrade the image quality** and is **the primary source of radiation exposure to operator and staff**



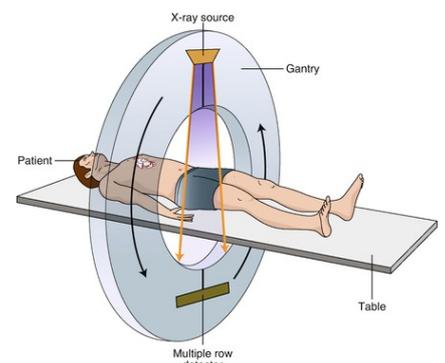
27 / 55



The physics of CAT scanning.

The acronym CAT stands for computerized axial tomography or computer assisted tomography.

- Uses a narrow beam of x-rays is aimed at a patient and quickly rotated around the body, producing signals that are processed by the machine's computer to generate cross-sectional images—or "slices" of the body.
- These slices are called tomographic images and contain more detailed information than conventional x-rays.
- Once a number of successive slices are collected by the machine's computer, they can be digitally "stacked" together to form a three-dimensional image of the patient that allows for easier identification and location of basic structures as well as possible tumors or abnormalities.
- The thickness of the tissue represented in each image slice can vary depending on the CT machine used, but usually ranges from 1-10 millimeters.



Each time the x-ray source completes one full rotation, the CT computer uses sophisticated mathematical techniques to construct a 2D image slice of the patient.

28 / 55

X-rays: Linear Accelerator.

The linear accelerator uses microwave technology (similar to that used for radar) to accelerate electrons in a part of the accelerator called the "wave guide," then allows these electrons to collide with a heavy metal target to produce high-energy x-rays.

Applications in radiotherapy



29 / 55

LASER

The acronym **LASER** stands for:

Light

Amplification by

Stimulated

Emission of

Radiation



30 / 55

Properties of Laser

- The light emitted from a laser is **monochromatic**, that is, it is of one color/wavelength. In contrast, ordinary white light is a combination of many colors (or wavelengths) of light.
- Lasers emit light that is highly **directional**, that is, laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light, such as from a light bulb, is emitted in many directions away from the source.
- The light from a laser is said to be **coherent**, which means that the wavelengths of the laser light are in phase in space and time. Ordinary light can be a mixture of many wavelengths.

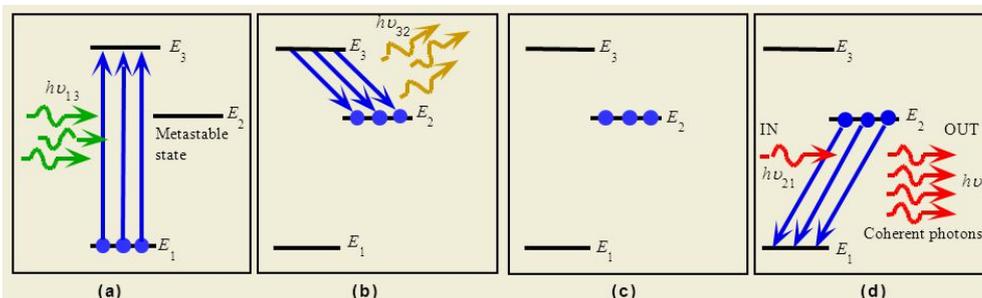
These three properties of laser light are what can make it more hazardous than ordinary light. Laser light can deposit a lot of energy within a small area.

31 / 55

Laser basics

Laser principles

- **Stimulated absorption:** Excite the atoms from E_1 to E_3 , this is called optical pumping as shown in (a)
- Spontaneous emission from E_3 to E_2 rapidly emitting ΔE_{32} as shown in (b)
- E_2 is a metastable state (long lived state 10^{-7} to 10^{-6} seconds), atoms from E_2 will not decay rapidly as shown in (c)
- Condition where there are a lot of atoms in E_2 , is called **population inversion** achieved between E_2 and E_1 as shown in (c)
- An incident photon can cause the atom to return to the ground state without being absorbed, this is called **stimulated emission** as shown in (d)
- Therefore, you have two photons with identical energy, the emitted photon and the incident photon. They both are in phase and travel in the same direction and this is called **light amplification** as shown in (d)



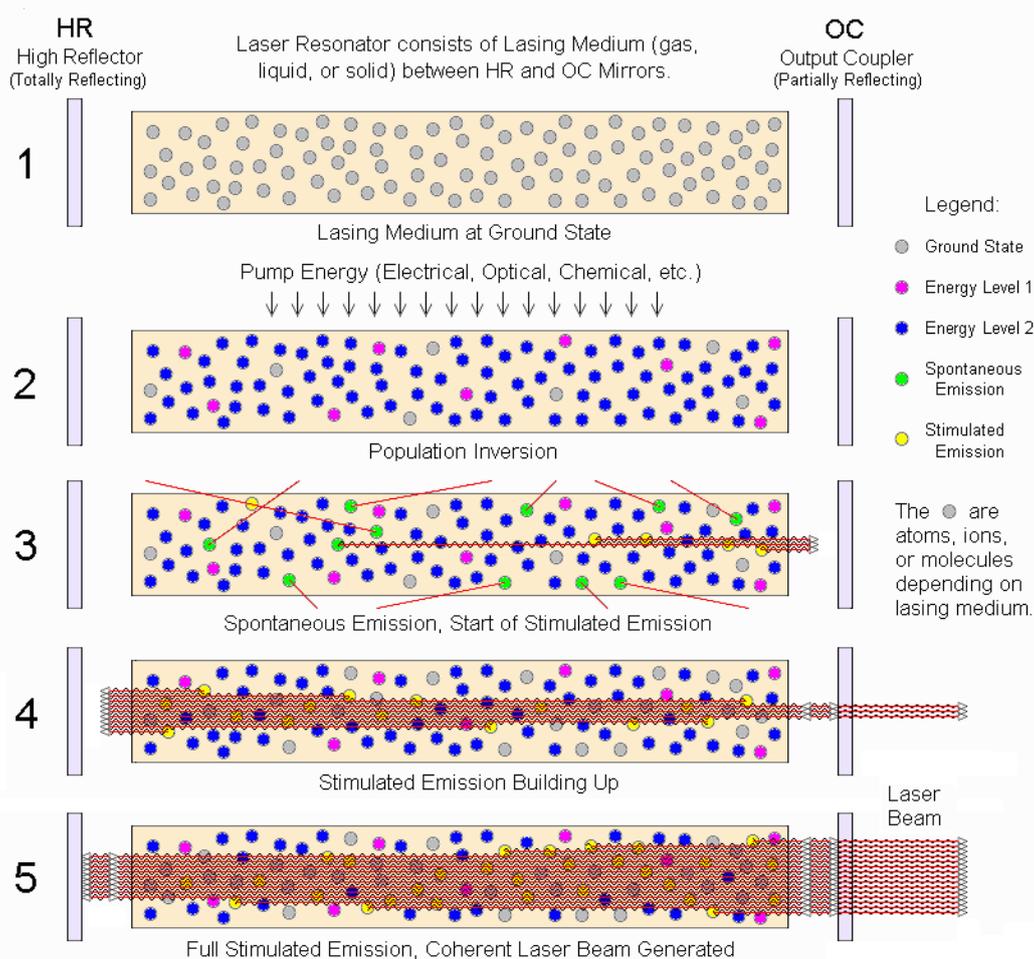
32 / 55

Laser basics: Conditions for build-Up of photons

- The system must be in a state of population inversion, a situation can be caused where there are more electrons in excited states than in the ground state
- The excited state of the system must be a metastable state
- In this case, the population inversion can be established and stimulated emission is likely to occur before spontaneous emission
- The emitted photons must be confined in the system long enough to enable them to stimulate further emission
- This is achieved by using reflecting mirrors

33 / 55

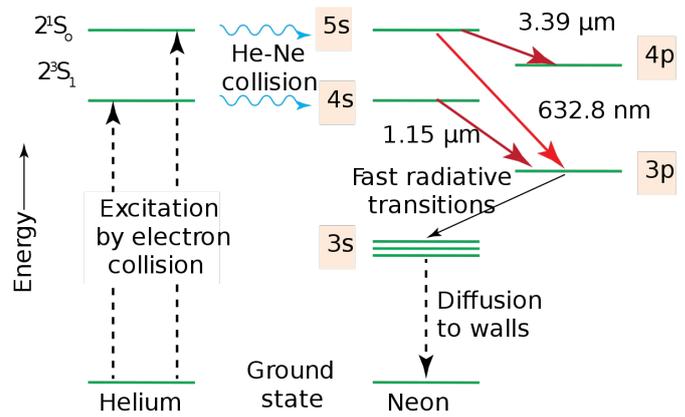
Laser basics



34 / 55

He-Ne Laser

- A helium-neon laser or He-Ne laser, is a type of gas laser whose gain medium consists of a mixture of 85% helium and 15% neon inside of a small electrical discharge.
- The best known and most widely used He-Ne laser operates at a wavelength of 632.8 nm, in the red part of the visible spectrum.



Mechanism:

- The mechanism producing population inversion and light amplification in a HeNe laser plasma originates with inelastic collision of energetic electrons with ground state helium atoms in the gas mixture.
- These collisions excite helium atoms from the ground state to higher energy excited states.
- Because of a near coincidence between the energy levels of the two He metastable states, and the levels of neon, collisions between these helium metastable atoms and ground state neon atoms results in a selective and efficient transfer of excitation energy from the helium to neon.

35 / 55



Home made Laser system

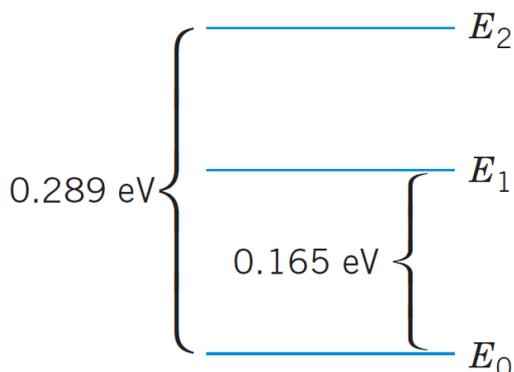
36 / 55



37 / 55

Problem 48

The drawing shows three energy levels of a laser that are involved in the lasing action. These levels are analogous to the levels in the Ne atoms of a He-Ne laser. The E_2 level is a metastable level, and the E_0 level is the ground state. The difference between the energy levels of the laser is shown in the drawing. (a) What energy (in eV per electron) must an external source provide to start the lasing action? (b) What is the wavelength of the laser light? (c) In what region of the electromagnetic spectrum (see Figure 24.9) does the laser light lie?



38 / 55

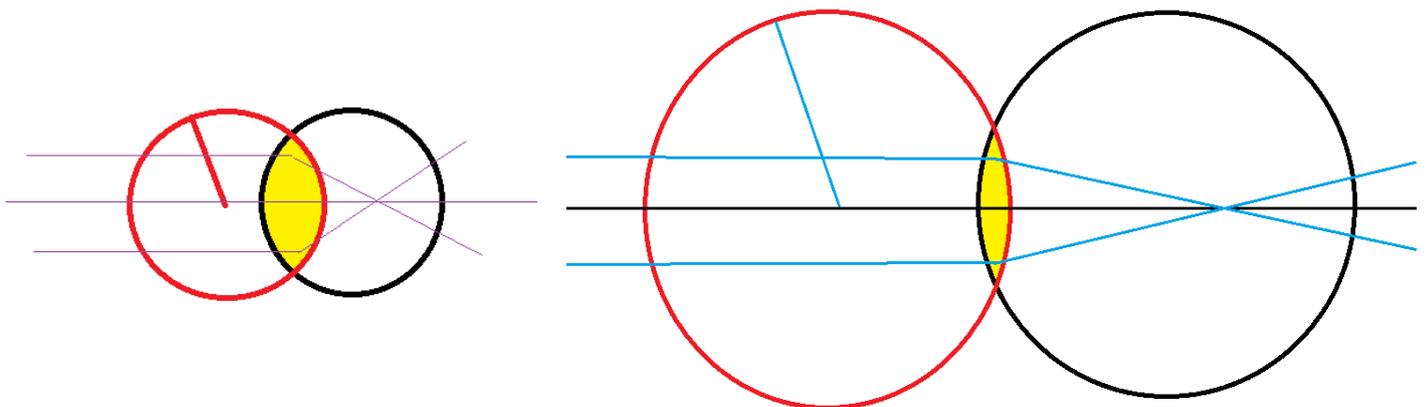
Problem 49

A laser peripheral iridotomy is a procedure for treating an eye condition known as narrow-angle glaucoma, in which pressure buildup in the eye can lead to loss of vision. A neodymium YAG laser (wavelength = 1064 nm) is used in the procedure to punch a tiny hole in the peripheral iris, thereby relieving the pressure buildup. In one application the laser delivers 4.1×10^{-3} J of energy to the iris in creating the hole. How many photons does the laser deliver?

39 / 55

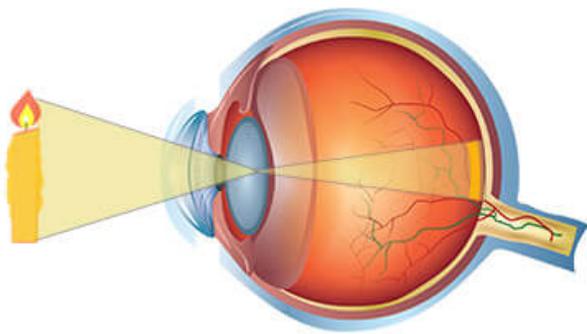
Laser vision correction: Radius of curvature and focal length

Focal length is proportional to the radius of curvature.

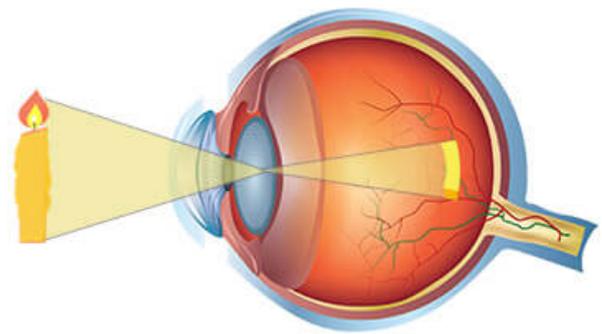


40 / 55

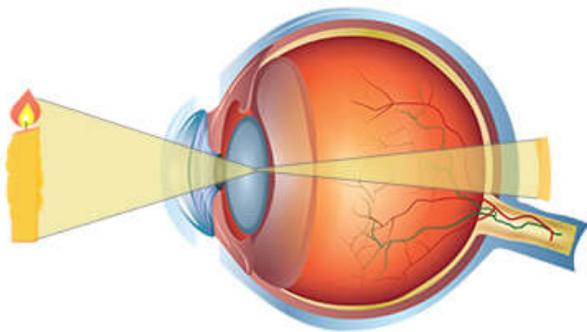
Lasik Laser vision correction: Radius of curvature and focal length



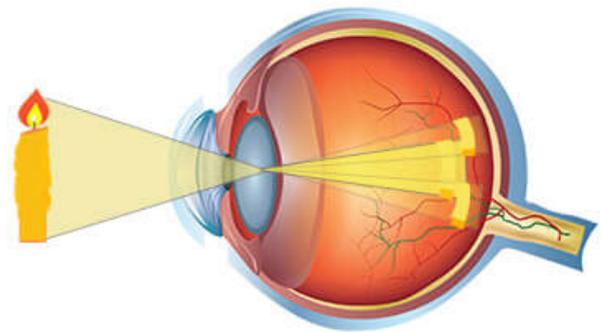
Normal Vision



Nearsighted



Farsighted

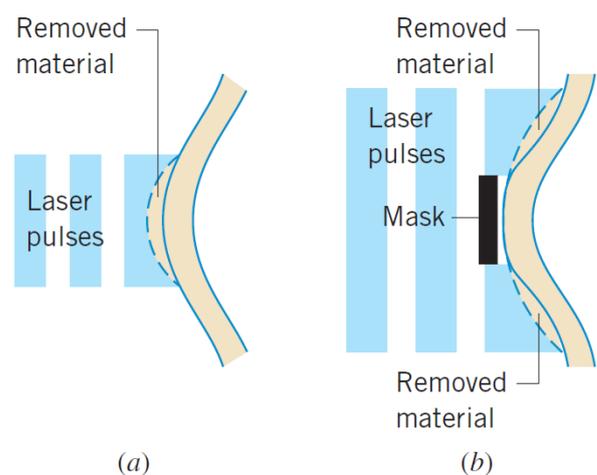


Astigmatic

41 / 55

Lasik Laser vision correction: Radius of curvature and focal length

- A laser-based procedure offers an alternative treatment for nearsightedness, farsightedness, and astigmatism that does not rely on lenses.
- It involves the use of a laser to remove small amounts of tissue from the cornea of the eye as shown in figure and thereby change its curvature.
- Changing the curvature of that boundary can correct deficiencies in the way the eye refracts light.



- (a) To correct for myopia (nearsightedness), a laser vaporizes tissue (dashed line) on the center of the cornea, thereby flattening it.
- (b) To correct for hyperopia (farsightedness), a laser vaporizes tissue on the peripheral region of the cornea, thereby steepening its contour.

42 / 55



Lasik versus PRK Eye Surgery.

- With **LASIK** (**Laser-Assisted in Situ Keratomileusis**), a thin flap is created on the cornea to allow reshaping of the tissue beneath. The flap, which isn't visible to others, will secure itself back to the eye, but it will always remain.



- **PRK** (**Photorefractive Keratectomy**), on the other hand, initially leaves the eye exposed. The cornea's outer layer is removed entirely before the reshaping process; that layer will grow back over time.

43 / 55

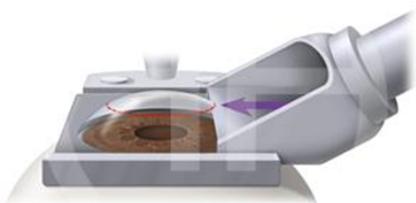


The physics of LASIK eye surgery: Flap creation

In LASIK, a thin flap is created on the cornea with a microkeratome or a femtosecond laser. This flap is lifted to expose the underlying corneal tissue and is replaced after the cornea is reshaped with an excimer laser.

Creating the flap can be done by:

1. Procedure uses a motor-powered blade known as a microkeratome to partially detach a thin flap (about 0.2 mm thick) in the front of the cornea



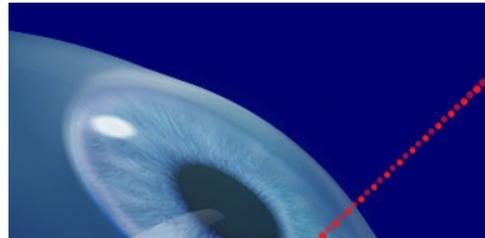
44 / 55



The physics of LASIK eye surgery: Flap creation

2. Using a Femtosecond Laser:

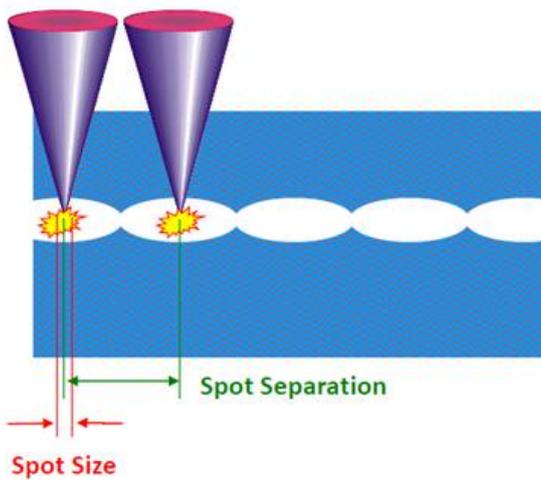
- Operating in the infrared laser with a wavelength of 1053nm to produce ultrashort pulses of energy to create adjacent areas of microcavitation (separation of tissue at the molecular level) at a specified depth in the cornea.
- The bubble created leaves a cavitation volume of 2 to 3 cubic μm .
- Thousands of these tiny bubbles, created in a raster pattern across the cornea, define the interface plane between the flap and the stromal bed.
- Bubbles are then stacked, starting around the edge of the interface, proceeding up through the epithelium to the corneal surface, creating the side cut and completing the flap creation.



45 / 55



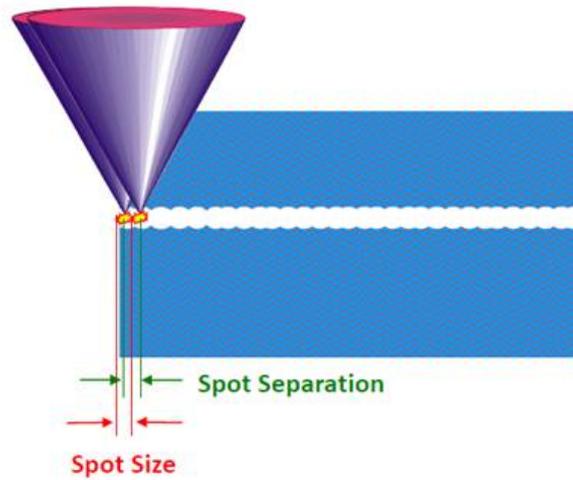
Flap creation- Femtosecond versus Nanosecond lasers



cutting process driven by mechanical forces (bubbles)

"High" Pulse Energy (μJ)

"Low" Pulse Frequency (kHz)



cutting process limited by focal spot size (many pulses needed)

(nJ) "Low" Pulse Energy

(MHz) "High" Pulse Frequency

Reducing the pulse duration reduces the amount of collateral tissue damage. In fact, collateral damage with FS (10^{-15}s) laser is 106 times less than with the Nd:YAG laser compared to the nanosecond lasers. Pulse frequency is the number of pulses per second.

46 / 55



The physics of LASIK eye surgery: Flap creation

A femtosecond laser is a laser which emits optical pulses with a duration well below 1 ps (\rightarrow ultrashort pulses), i.e., in the domain of femtoseconds ($1 \text{ fs} = 10^{-15} \text{ s}$). It thus also belongs to the category of ultrafast lasers or ultrashort pulse lasers (which also include picosecond lasers).

Advantages of femtosecond laser LASIK:

In addition to putting patients at greater ease (knowing that no blade will be used on their eye) advantages of bladeless, femtosecond laser LASIK include:

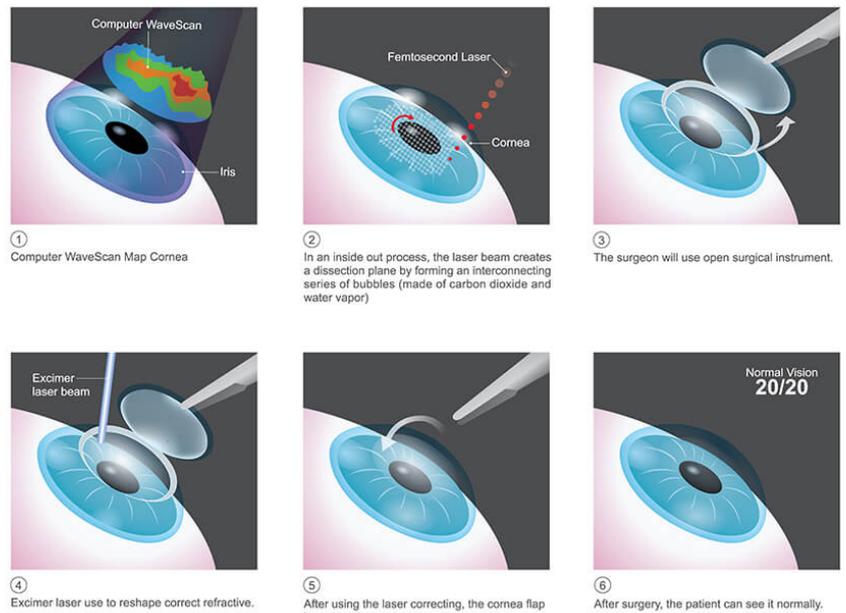
- More predictable corneal flap thickness
- Decreased risk of corneal abrasions during surgery
- Decreased risk of induced astigmatism after LASIK
- Also, in some cases, a femtosecond laser may make it possible to create a thinner corneal flap, which could enable the surgeon to safely correct higher amounts of nearsightedness.

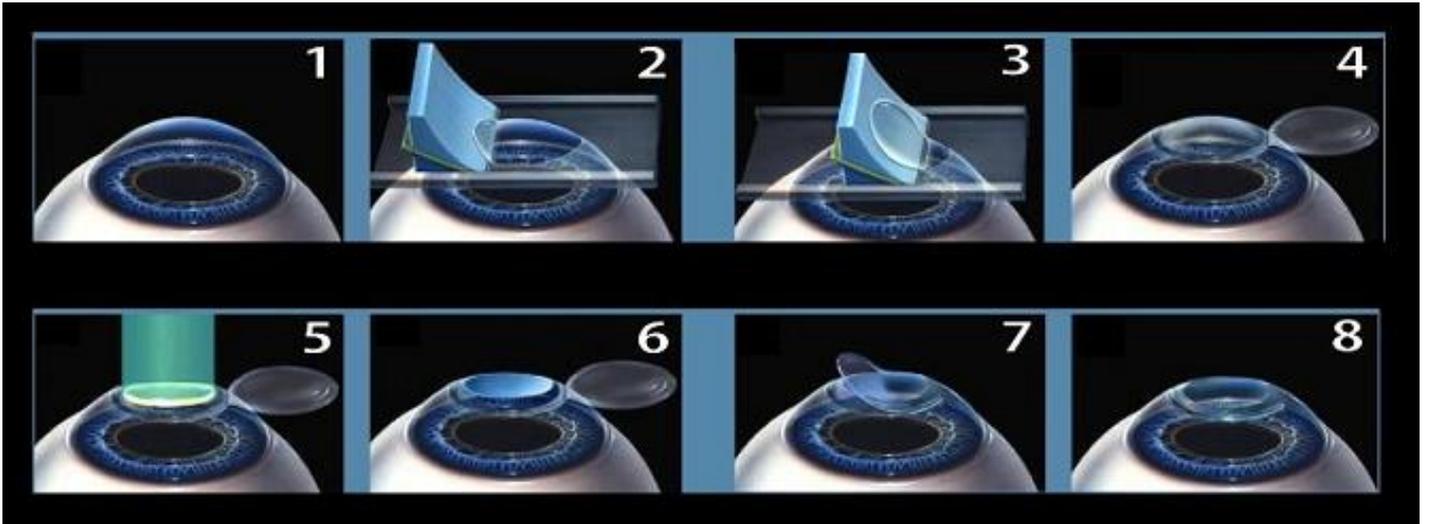


Reshaping the Cornea

The laser light in the PRK and LASIK techniques is pulsed and comes from an ultraviolet excimer laser that produces a wavelength of 193 nm. The cornea absorbs this wavelength extremely well, so that weak pulses can be used, leading to highly precise and controllable removal of corneal tissue. Typically, 0.1 to $0.5 \mu\text{m}$ of tissue is removed by each pulse without damaging adjacent layers.

Blade-Free LASIK (Femtosecond Laser)







The physics of SMILE eye surgery

Small Incision Lenticule Extraction (SMILE) is an impressive laser treatment option for patients with nearsightedness or astigmatism, as well as those with contact lens intolerance,

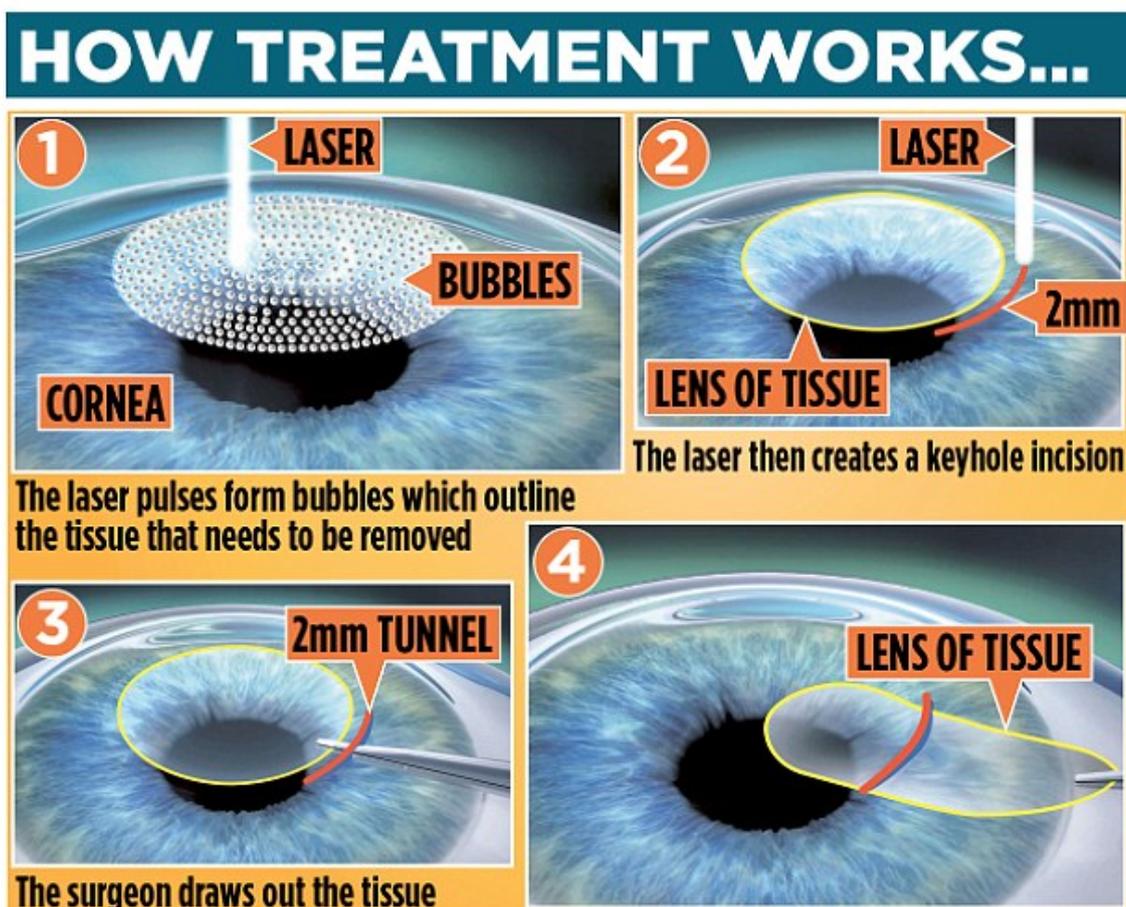
- The minimally invasive SMILE procedure only takes a few minutes to correct a problem (comparable to LASIK and refractive surgery correction)
- requiring only a small, precise opening to correct your cornea
- The actual exposure time to the laser averages less than 10 seconds with a femtosecond laser
- It's a gentle, comfortable, stress-free patient experience with a remarkably fast visual recovery for your eye.

In the SMILE procedure, the surgeon uses a femtosecond laser to create a small, lens-shaped bit of tissue (lenticule) within the cornea. Then, with the same laser, a small arc-shaped incision is made in the surface of the cornea. The surgeon extracts the lenticule through this incision and discards it.

51 / 55



The physics of SMILE eye surgery



52 / 55



The physics of photodynamic therapy for cancer.

- In the treatment of cancer, the laser is being used along with light-activated drugs in photodynamic therapy.
- The procedure involves administering the drug intravenously, so that the tumor can absorb it from the bloodstream, the advantage being that the drug is then located right near the cancer cells.
- When the drug is activated by laser light, a chemical reaction ensues that disintegrates the cancer cells and the small blood vessels that feed them.

Photodynamic therapy (PDT) is a treatment that uses a drug, called a photosensitizer or photosensitizing agent, and a particular type of light. When photosensitizers are exposed to a specific wavelength of light, they produce a form of oxygen that kills nearby cells

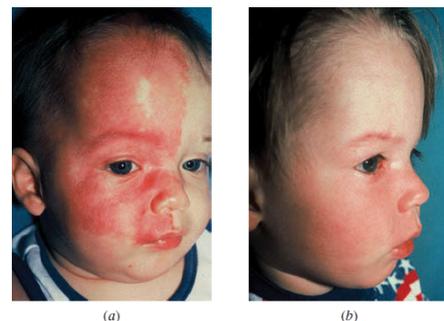
53 / 55



The physics of removing port-wine stains.

Another medical application of the laser is in the treatment of congenital capillary malformations known as port-wine stains.

- Affect 0.3% of children at birth.
- These birthmarks are usually found on the head and neck.
- Preferred treatment for port-wine stains now utilizes a pulsed dye laser.
- The light is absorbed by oxyhemoglobin in the malformed capillaries, which are destroyed in the process without damage to adjacent normal tissue.
- Eventually the destroyed capillaries are replaced by normal blood vessels, which causes the port-wine stain to fade.



A patient with a port-wine stain (a) before and (b) after treatment using a pulsed dye laser. (Courtesy Gerald Goldberg, MD, Pima Dermatology)

54 / 55

Homework Problems: Homework: 12, 13, 26, 45, 47

The End

Nuclear Physics and Radioactivity (Chapter 31)

- 1 Nuclear Structure
- 2 The Strong Nuclear Force and the Stability of the Nucleus
- 3 The Mass Defect of the Nucleus and Nuclear Binding Energy
- 4 Radioactivity
 - Alpha Decay
 - Beta Decay
 - Neutrino
 - Electron capture
 - Q-Value: Beta Decay and Electron capture
 - Gamma Decay
- 5 Radioactive Decay and Activity
- 6 Medical Applications of Radioactivity
 - Radiation Therapy
 - The Physics of Gamma Knife Radiosurgery
 - The physics of an Exercise Thallium Heart Scan
 - The Physics of Brachytherapy Implants
- 7 Radiation detectors

1 / 44

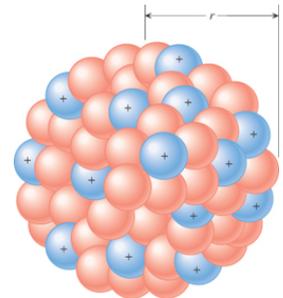
Nuclear Structure.

The atomic nucleus consists of positively charged protons and neutral neutrons.

Identifying Variables:

$$\underbrace{A}_{\text{Number of proton and neutrons}} = \underbrace{Z}_{\text{Number of proton}} + \underbrace{N}_{\text{Number of neutrons}}$$

A is the mass number
 Z is the atomic number



Symbol for an element is: ${}^A_Z\text{X}$

Table 31.1 Properties of Select Particles

Particle	Electric Charge (C)	Mass	
		Kilograms (kg)	Atomic Mass Units (u)
Electron	-1.60×10^{-19}	$9.109\,382 \times 10^{-31}$	$5.485\,799 \times 10^{-4}$
Proton	$+1.60 \times 10^{-19}$	$1.672\,622 \times 10^{-27}$	1.007 276
Neutron	0	$1.674\,927 \times 10^{-27}$	1.008 665
Hydrogen atom	0	$1.673\,534 \times 10^{-27}$	1.007 825

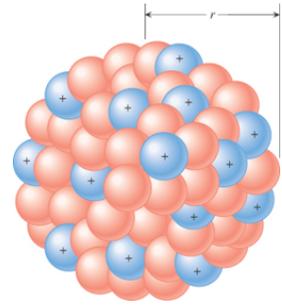
2 / 44

Approximate size of a Nucleus

$$r = (1.2 \times 10^{-15} \text{ meter}) A^{1/3}$$

Conceptual Example: Nuclear Density

It is well known that lead and oxygen contain different atoms and that the density of solid lead is much greater than gaseous oxygen. Using the equation, decide whether the density of the nucleus in a lead atom is greater than, approximately equal to, or less than that in an oxygen atom.



$$r = (1.2 \times 10^{-15} \text{ meter}) A^{1/3}$$

$$\rho = \frac{M}{V} = \frac{Am_{neutron}}{\frac{4}{3}\pi ((1.2 \times 10^{-15} \text{ meter}) A^{1/3})^3}$$

$$\rho = 2.31 \times 10^{17} \text{ kg/m}^3$$

Nuclear density are always the same

Therefore the density of nuclear matter is $2.3 \times 10^{17} \text{ kg/m}^3$. Since the mass of the Earth is only $6 \times 10^{24} \text{ kg}$ it would take only 2.6×10^7 cubic meters of nuclear material to equal the mass of the Earth. It is equivalent to sphere of radius 184 m of nuclear matter.

3 / 44

Useful quantities

In calculations with nuclear physics , it is customary to use the atomic mass unit (**u**) instead of the kilogram and its energy equivalent.

$1\text{u} = 1.6605 \times 10^{-27} \text{ kg}$ the energy equivalent of one atomic mass unit can be determined by:

$$\Delta E_o = (\Delta m)c^2 = (1.6605 \times 10^{-27} \text{ kg})(2.9979 \times 10^8 \text{ m/s})^2 = 1.4924 \times 10^{-10} \text{ J}$$

In electron volts, therefore, one atomic mass unit is equivalent to

$$1\text{u} = (1.4924 \times 10^{-10} \text{ J}) \left(\frac{1\text{eV}}{1.6022 \times 10^{-19} \text{ J}} \right) = 931.5 \text{ MeV}$$

4 / 44

Isotopes

Isotopes: Nuclei that contain the same number of protons, but a different number of neutrons, are known as isotopes.

Abundance of carbon isotopes in nature

Isotope	Abundance	Stability
${}^1_6\text{C}$	98.89 %	Stable
${}^{13}_6\text{C}$	1.11 %	Stable
${}^{14}_6\text{C}$	10^{-12} %	Unstable

Check Your Understanding 1

Two nuclei differ in their numbers of protons and their numbers of neutrons. Which one or more of the following statements is/are true? (a) They are different isotopes of the same element. (b) They have the same electric charge. (c) They could have the same radii. (d) They have

5 / 44

Check Your Understanding 2

A material is known to be an isotope of lead, although the particular isotope is not known. From such limited information, which of the following quantities can you specify? (a) Its atomic number (b) Its neutron number (c) Its atomic mass number

Check Your Understanding 3

Two nuclei have different nucleon numbers A_1 and A_2 . Are the two nuclei necessarily isotopes of the same element? (a) Yes, (b) No

Check Your Understanding 4

Can two nuclei have the same radius, even though they contain different numbers of protons and different numbers of neutrons? (a) Yes, (b) No

6 / 44

Question

Consider the nucleus ${}^{234}_{91}\text{Pa}$ (Protactinium) Which one of the following statements is true?

- (A) This isotope contains an equal number of protons and neutrons.
- (B) This isotope contains 91 neutrons and 143 protons.
- (C) This isotope contains 143 neutrons and 91 protons.
- (D) This isotope contains 234 neutrons and 91 protons.
- (E) This isotope contains 91 neutrons and 234 protons.

7 / 44

What Holds a Nucleus Together?

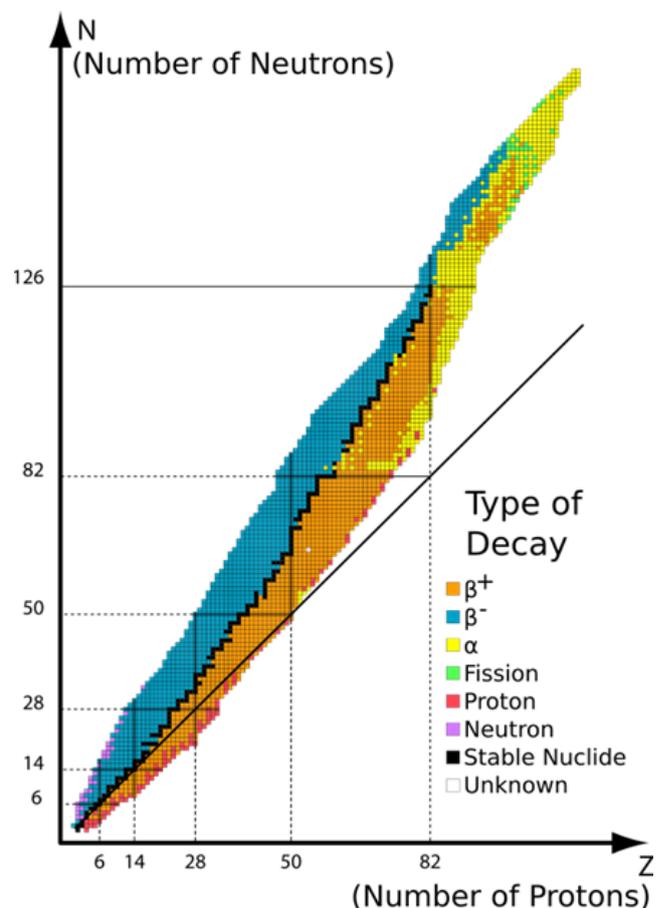
The mutual repulsion of the protons due to the Electric Force should push the nucleus apart.

What then, holds the nucleus together?

A stronger nuclear force within the Nucleus

Stability of the Nucleus

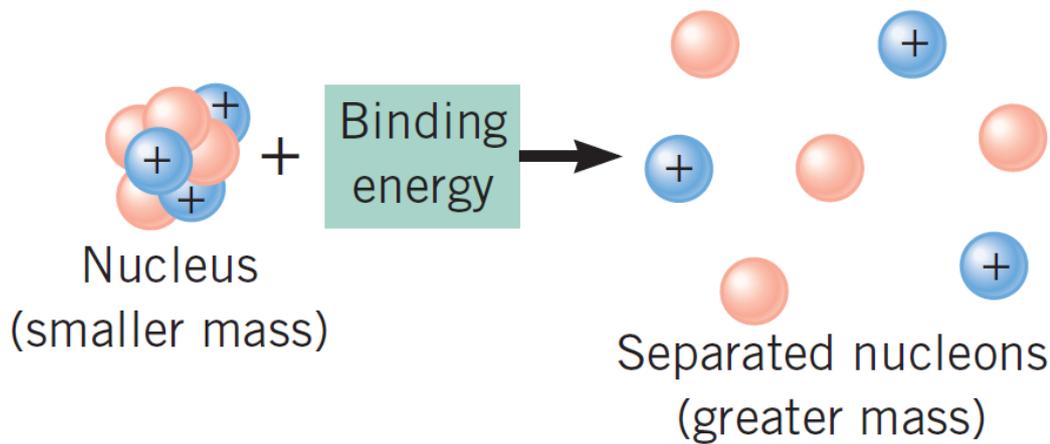
- As nuclei get larger, more neutrons are required for stability.
- The neutrons act like glue without adding more repulsive force.
- For “small” elements ratio $N/P \sim 1$
- For “large” element ratio of $N/P \sim 2$



8 / 44

The Mass Defect of the Nucleus and Nuclear Binding Energy

- The mass of a nucleus is less than the sum of the masses of the individual protons and neutrons because of the binding energy of the nucleus.
- An amount of energy equal to the binding energy must be supplied to the nucleus to break it apart into individual protons and neutrons.



9 / 44

The Mass Defect of the Nucleus and Nuclear Binding Energy

The binding energy can be calculated from conservation of energy and the Einstein mass-energy equivalence principle:

For a given atom ${}^A_Z\mathbf{X}$

The binding energy is:

$$E_b(\text{MeV}) = \underbrace{\left[ZM({}^1_1\mathbf{H}) + Nm_n - M({}^A_Z\mathbf{X}) \right]}_{\text{Mass defect}} \times 931.494 \text{ MeV}$$

Where: $M({}^1_1\mathbf{H})$ is the atomic mass of the neutral hydrogen atom.

$M({}^A_Z\mathbf{X})$ represents the atomic mass of an atom.

m_n is the mass of the neutron.

The masses are expressed in atomic mass units.

$$\text{Binding energy} = (\text{Mass defect})c^2$$

10 / 44

Problem 15

For lead $^{206}_{82}\text{Pb}$ (atomic mass = 205.974 440 u) obtain (a) the mass defect in atomic mass units, (b) the binding energy (in MeV), and (c) the binding energy per nucleon (in MeV/nucleon).

$$\Delta m = \left[ZM({}_1^1\text{H}) + Nm_n - M({}_Z^AX) \right]$$

$$\Delta m = [82(1.007825) + 124(1.008665) - 205.974440] = 1.74167u$$

Binding energy =

$$1.74167u \frac{931.5\text{MeV}}{1u} = 1622.36 \text{ MeV}$$

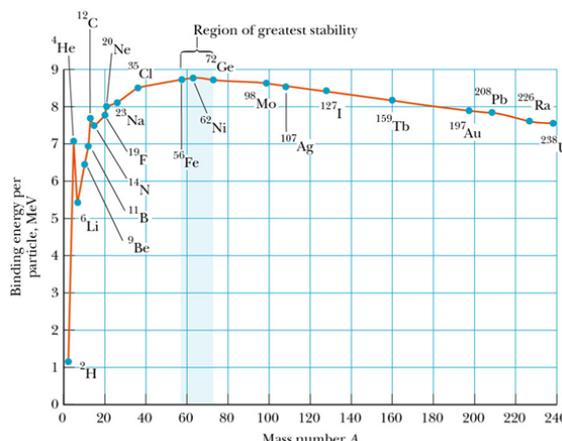
Binding energy/Nucleon =

$$\frac{1622.36\text{MeV}}{206} = 7.87 \text{ MeV}$$

11 / 44

Binding Energy per Nucleon

- The binding energy per nucleon generally increases rapidly with increasing A up to about $A \sim 60$ and then more slowly decreases with further increase in A .
- This means that the nuclei with intermediate masses are the most stable compared with the light and heavy nuclei.
- The binding energy per nucleon is shown below as a function of A .
- This figure suggests that we can convert mass to energy by combining lighter nuclei to make nuclei of intermediate size (fusion) or breaking apart heavy nuclei into nuclei of intermediate size (fission).



© 2006 Brooks/Cole - Thomson

12 / 44

Radioactivity: General Rules

- When an unstable or radioactive nucleus disintegrates spontaneously, certain kinds of particles and/or high-energy photons are released.
- These particles and photons are collectively called “rays.” Three kinds of rays are produced by naturally occurring radioactivity: α rays, β rays, and γ rays.

Radioactive decay must obey the conservation laws of physics. The following list shows the property with which each law deals:

- Conservation of energy/mass
- Conservation of linear momentum
- Conservation of angular momentum
- Conservation of electric charge
- Conservation of nucleon number

In all radioactive decay processes it has been observed that:

- The sum of the mass numbers A must be the same on both sides of the equation
- The sum of the atomic numbers Z must be the same on both sides of the equation

13 / 44

Alpha Decay

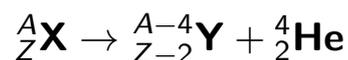
When a nucleus emits an alpha particle it loses two protons and two neutrons

- N decreases by 2
- Z decreases by 2
- A decreases by 4

Symbolically:

\mathbf{X} is called the parent nucleus

\mathbf{Y} is called the daughter nucleus



The disintegration energy Q of a system is defined as

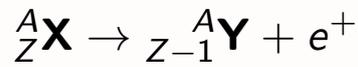
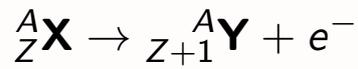
$$Q = (M_X - M_Y - M_\alpha)c^2$$

- The disintegration energy appears in the form of kinetic energy in the daughter nucleus and the alpha particle
- It is sometimes referred to as the Q value of the nuclear decay

14 / 44

Beta Decay

During beta decay, the daughter nucleus has the same number of nucleons as the parent, but the atomic number is changed by one



The emission of the electron or positron is from the nucleus
Beta decay is not completely described by these equations

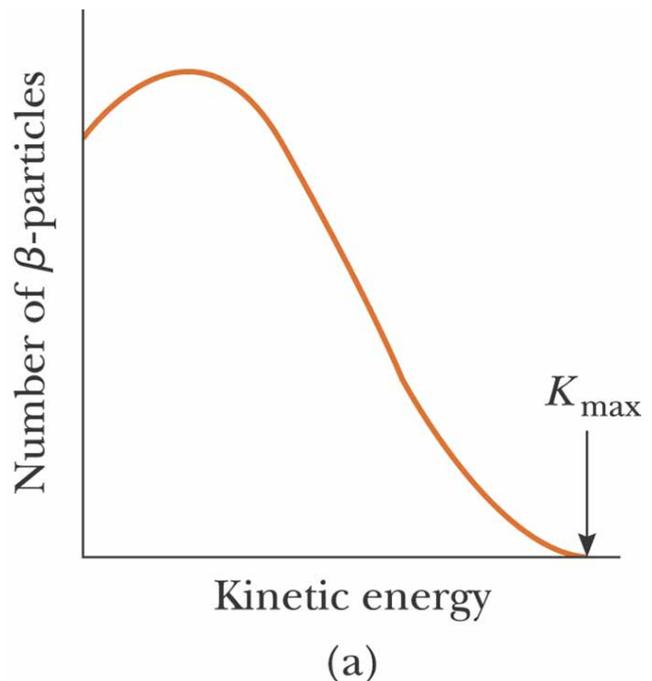
About the decay

- The nucleus contains protons and neutrons.
- The process occurs when a neutron is transformed into a proton or a proton changes into a neutron
- Electron or positron is created in the process of the decay

15 / 44

Beta Decay – Particle Energy

- The energy released in the decay process should almost all go to kinetic energy of the β particle
- Since the decaying nuclei all have the same rest mass, the Q value should be the same for all decays
- Experiments showed a range in the amount of kinetic energy of the emitted particles



©2004 Thomson - Brooks/Cole

This means that conservation laws are violated!!

16 / 44

Neutrino: Beta Decay

To account for this missing energy:

- In 1930 Pauli proposed the existence of another particle
- Enrico Fermi later named this particle the neutrino
- Properties of the neutrino
 - ▶ Zero electrical charge
 - ▶ Mass much smaller than the electron, probably not zero
 - ▶ Spin of 1/2
 - ▶ Very weak interaction with matter and so is difficult to detect



ν is the symbol for the neutrino

$\bar{\nu}$ is the symbol for the antineutrino

To summarize, in beta decay, the following pairs of particles are emitted

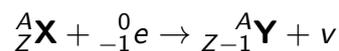
- An electron and an antineutrino
- A positron and a neutrino

17 / 44

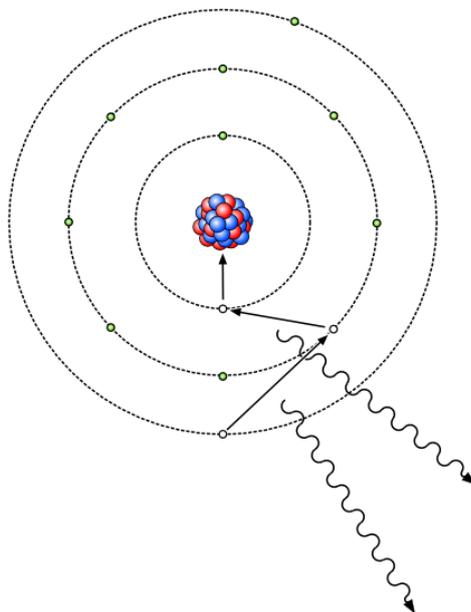
Electron capture

Electron capture is a process that competes with e^+ decay.

In this case, a parent nucleus captures one of its own orbital electrons and emits a neutrino:



In most cases, a K-shell electron is captured, so this is often referred to as K capture.



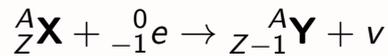
18 / 44

Beta Decay Q-value

Q Values for Beta Decay:

For e^- decay and electron capture, the Q value is

$$Q = (M_X - M_Y)c^2$$



For e^+ decay, the Q value is:

$$Q = (M_X - M_Y - 2m_e)c^2$$



The extra term, $-2m_e c^2$, is due to the fact that the atomic number of the parent decreases by one when the daughter is formed.

To form a neutral atom, the daughter sheds one electron

If Q is negative, the decay will not occur

19 / 44

Beta Decay

The fundamental process of:

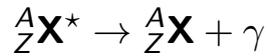
- e^- decay is a neutron changing into a proton, an electron and an antineutrino
- In e^+ , the proton changes into a neutron, positron and neutrino
- This can only occur within a nucleus
- It cannot occur for an isolated proton since its mass is less than the mass of the neutron

20 / 44

Gamma Decay

Gamma rays are given off when an excited nucleus decays to a lower energy state.

The decay occurs by emitting a high-energy photon called gamma-ray photons.



The X^* indicates a nucleus in an excited state.

Typical half-life is 10^{-10} s

TABLE 44.3

Various Decay Pathways

Alpha decay	${}^A_Z\mathbf{X} \rightarrow {}^{A-4}_{Z-2}\mathbf{Y} + {}^4_2\mathbf{He}$
Beta decay (e^-)	${}^A_Z\mathbf{X} \rightarrow {}^A_{Z+1}\mathbf{Y} + e^- + \bar{\nu}$
Beta decay (e^+)	${}^A_Z\mathbf{X} \rightarrow {}^A_{Z-1}\mathbf{Y} + e^+ + \nu$
Electron capture	${}^A_Z\mathbf{X} + {}^0_{-1}\mathbf{e} \rightarrow {}^A_{Z-1}\mathbf{Y} + \nu$
Gamma decay	${}^A_Z\mathbf{X}^* \rightarrow {}^A_Z\mathbf{X} + \gamma$

© Thomson Higher Education

21 / 44

Radioactive Materials

Radionuclides	Radiation being emitted	Half-life
Thorium-232 (Th-232)	α, γ	14.1 billion years
Uranium-238 (U-238)	α, γ	4.5 billion years
Potassium-40 (K-40)	β, γ	1.3 billion years
Plutonium-239 (Pu-239)	α, γ	24,000 years
Carbon-14 (C-14)	β	5,730 years
Cesium-137 (Cs-137)	β, γ	30 years
Strontium-90 (Sr-90)	β	29 years
Tritium (H-3)	β	12.3 years
Cesium-134 (Cs-134)	β, γ	2.1 years
Iodine-131 (I-131)	β, γ	8 days
Radon-222 (Rn-222)	α, γ	3.8 days

Artificial radionuclides are shown in red letters.

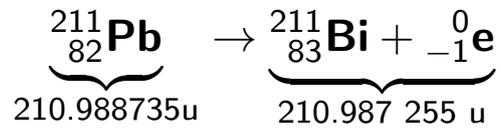
α : α (alpha) particles, β : β (beta) particles, γ : γ (gamma)-rays

22 / 44

Problem 22

Find the energy that is released when a nucleus of lead ${}^{211}_{82}\text{Pb}$ (atomic mass = 210.988 735 u) undergoes β decay to become bismuth ${}^{211}_{83}\text{Bi}$ (atomic mass = 210.987 255 u).

Answer:



When a ${}^{211}_{82}\text{Pb}$ nucleus decays into a bismuth ${}^{211}_{83}\text{Bi}$ nucleus, the number of orbital electrons in the bismuth atom is the same (82) as that in the parent lead atom; thus, the bismuth atom is missing one orbital electron. However, the atomic mass for bismuth ${}^{211}_{83}\text{Bi}$ (210.987 255u) includes all 83 electrons for the neutral atom.

$$\Delta E = (210.988735\ \text{u} - 210.987255\ \text{u}) \left(\frac{931.5\ \text{MeV}}{1\ \text{u}} \right) = 1.38\ \text{MeV}$$

23 / 44

Radioactive Decay and Activity.

- Radioactivity is the spontaneous emission of radiation
- Discovered by Becquerel in 1896
- Many experiments were conducted by Becquerel and the Curies

The number of particles that decay in a given time is proportional to the total number of particles in a radioactive sample.

$$\frac{dN}{dt} = -\lambda N$$

$$N = N_0 e^{-\lambda t}$$

λ is called the decay constant and determines the rate at which the material will decay

N is the number of undecayed radioactive nuclei present

N_0 is the number of undecayed nuclei at time $t = 0$

Radioactivity: Decay curve

The decay curve follows the equation

$$N = N_0 e^{-\lambda t}$$

The half-life is defined as the time interval during which half of a given number of radioactive nuclei decay:

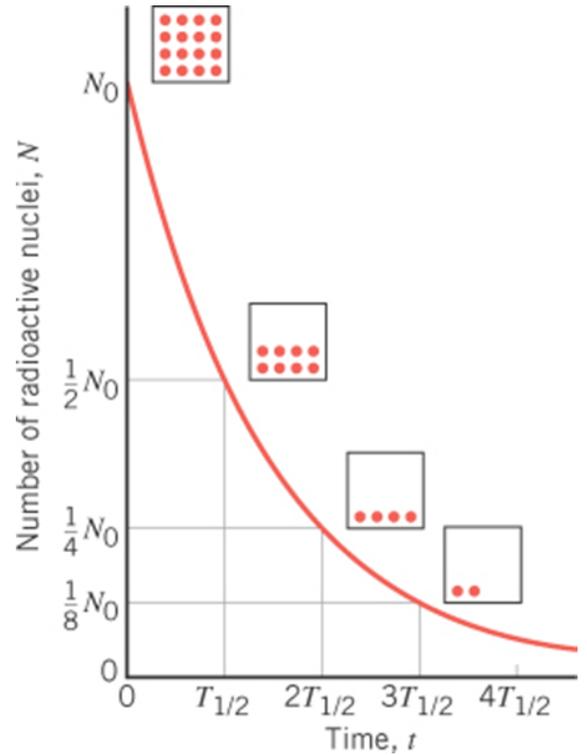
$$T_{1/2} = \frac{\ln 2}{\lambda}$$

The decay rate R of a sample is defined as the number of decays per second

$$R = \left| \frac{dN}{dt} \right| = \lambda N = R_0 e^{-\lambda t}$$

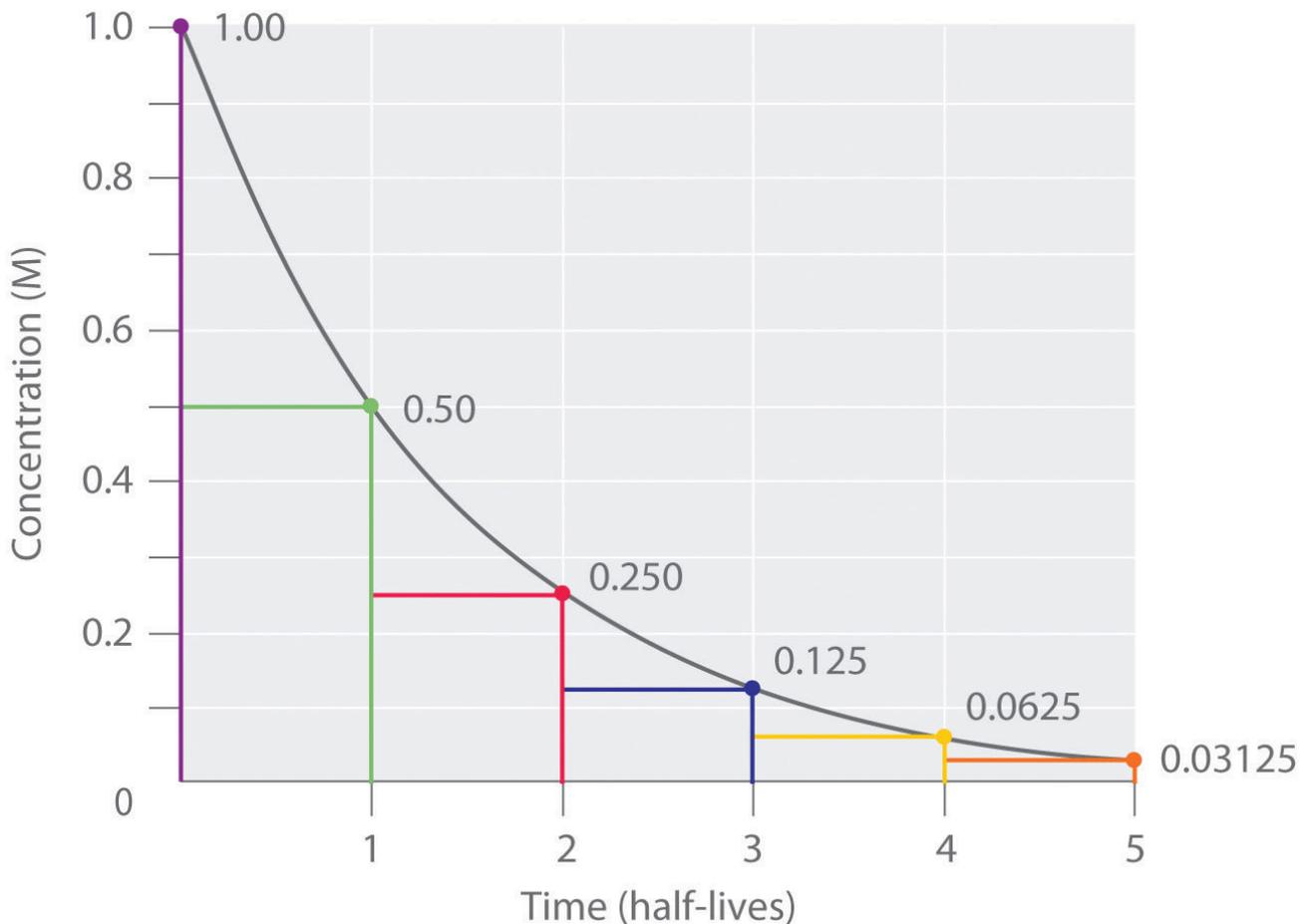
$R_0 = N_0 \lambda$ is the decay rate at $t = 0$

The decay rate is often referred to as the activity of the sample



25 / 44

Radioactivity: Decay curve



26 / 44



The unit of activity, R , is the curie (Ci)

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ decays/s}$$

The SI unit of activity is the becquerel (Bq)

$$1 \text{ Bq} = 1 \text{ decay/s}$$

$$\text{Therefore, } 1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$$

27 / 44

Question

An isotope of cesium has a half-life of two years. If we had 100 grams of this isotope today, how much would we have left ten years from now?

- A about three grams
- B about six grams
- C about twelve grams
- D about twenty-five grams
- E about fifty grams

28 / 44

Question

After 6400 years of undergoing alpha decay, a sample contains only 6.25% of the radium nuclei it initially had. What is the half-life of these radium nuclei?

- A 160 years
- B 6000 years
- C 3200 years
- D 800 years
- E 1600 years

29 / 44

Focus on Concepts: 9

A nucleus can undergo α , β^- , or γ decay. For each type of decay, is the radius of the daughter nucleus greater than, less than, or about the same as the radius of the parent nucleus?

	α Decay	β^- Decay	γ Decay
(a)	Greater than	Greater than	About the same as
(b)	Greater than	Less than	About the same as
(c)	Less than	About the same as	Greater than
(d)	Less than	About the same as	About the same as
(e)	About the same as	Less than	Less than

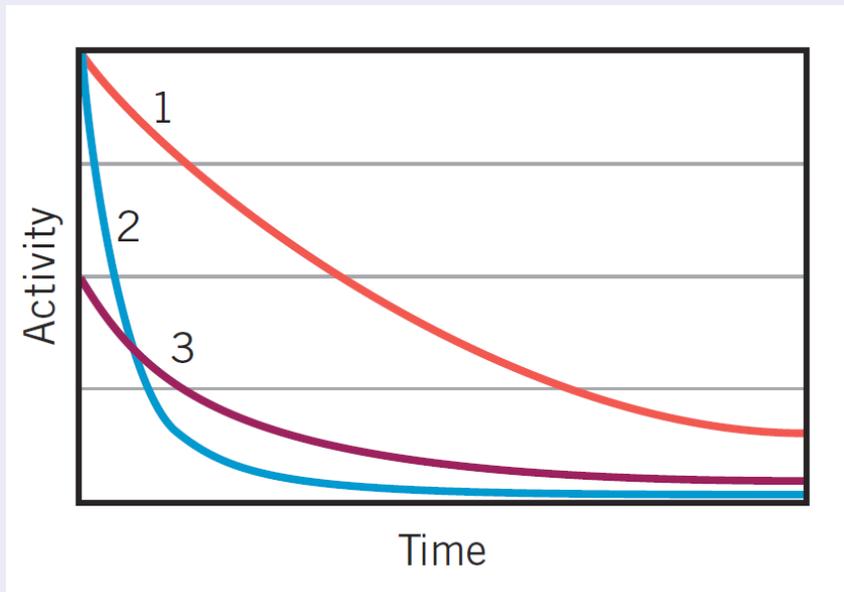
Answer: (d)

30 / 44

Focus on Concepts: 15

The drawing shows the activities of three radioactive samples. Rank the samples according to half-life, largest first.

(a) 2, 3, 1 (b) 1, 2, 3 (c) 3, 2, 1 (d) 1, 3, 2 (e) 3, 1, 2



31 / 44

Problem 20

Write the β decay process for carbon $^{14}_6\text{C}$, including the chemical symbols as well as the values of Z and A for the parent and daughter nuclei and the β particle.

32 / 44



What is radiation therapy? I



© MAYO FOUNDATION FOR MEDICAL EDUCATION AND RESEARCH. ALL RIGHTS RESERVED.

- Radiation therapy uses high-energy particles or waves, such as x-rays, gamma rays, electron beams, or protons, to destroy or damage cancer cells.
- Cells normally grow and divide to form new cells. But cancer cells grow and divide faster than most normal cells.
- Radiation works by making small breaks in the DNA inside cells.

33 / 44



What is radiation therapy? II

- These breaks keep cancer cells from growing and dividing and cause them to die.
- Nearby normal cells can also be affected by radiation, but most recover and go back to working the way they should.
- Unlike chemotherapy, which usually exposes the whole body to cancer-fighting drugs, radiation therapy is usually a local treatment.
- Over time, the radiation damages cells that are in the path of its beam - normal cells as well as cancer cells.
- But radiation affects cancer cells more than normal cells.
- Cancer cells are very busy growing and multiplying activities that can be slowed or stopped by radiation damage.
- And because cancer cells are less organized than healthy cells, it's harder for them to repair the damage done by radiation.

34 / 44



What is radiation therapy? III

- So cancer cells are more easily destroyed by radiation, while healthy, normal cells are better able to repair themselves and survive the treatment.

35 / 44

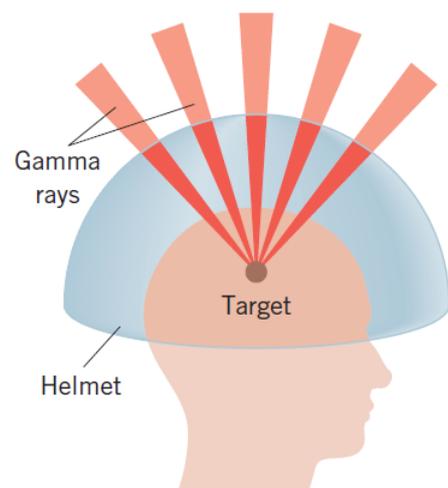


The physics of Gamma Knife radiosurgery I.

- Gamma Knife radiosurgery is becoming a very promising medical procedure for treating certain problems of the brain, including benign and cancerous tumors as well as blood vessel malformations.
- The procedure, which involves no knife at all, uses powerful, highly focused beams of γ rays aimed at the tumor or malformation.
- The γ rays are emitted by a radioactive cobalt-60 source.
- The patient wears a protective metal helmet that is perforated with many small holes.



(a)



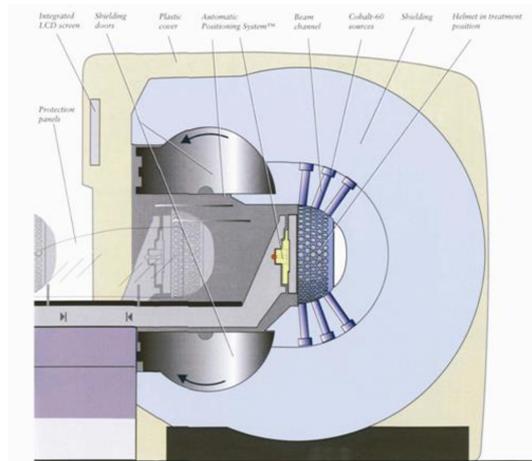
(b)

Figures:(a) In Gamma Knife radiosurgery, a protective metal helmet containing many small holes is placed on the patient's head. (b) The holes focus the beams of γ rays to a tiny target within the brain.

36 / 44



The physics of Gamma Knife radiosurgery II.



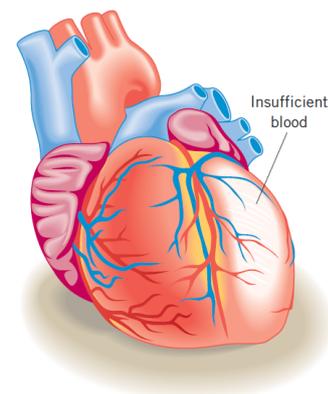
- The holes focus the γ rays to a single tiny target within the brain.
- The target tissue thus receives a very intense dose of radiation and is destroyed, while the surrounding healthy tissue is undamaged.
- Gamma Knife surgery is a noninvasive, painless, and bloodless procedure that is often performed under local anesthesia.
- Hospital stays are 70 to 90% shorter than with conventional surgery, and patients often return to work within a few days.

37 / 44



The physics of an exercise thallium heart scan.

- Thallium scan: A method of examining the heart to obtain information about the blood supply to the heart muscle. The radioactive half-life of Tl-201 is 73.1h
- In the scan, special cameras (Gamma camera) take a series of pictures of the heart.
- The tracer(Thallium) attaches to the muscle cells of the heart so the imaging camera can take pictures of the heart muscles. If an area of the heart does not receive an adequate flow of blood, the cells in the underserved area do not receive as much tracer and it appears as a darker area on the picture taken by the camera.



Figures:(An exercise thallium heart scan indicates regions of the heart that receive insufficient blood during exercise.



38 / 44



The physics of brachytherapy implants. I



- Brachytherapy places radioactive sources inside the patient on a temporary or permanent basis to damage cancer cells' DNA and destroy their ability to divide and grow.
- The use of radioactive isotopes to deliver radiation to specific targets in the body is an important medical technique.

39 / 44



The physics of brachytherapy implants. II

- In treating cancer, for example, the method of delivery should ideally apply a high dose of radiation to a malignant tumor in order to kill it, while applying only a small (non-damaging) dose to healthy surrounding tissue.
- In this type of treatment, radioactive isotopes are formed into small seeds and implanted directly in the tumor according to a predesigned pattern.
- The energy and type of radiation emitted by the isotopes can be exploited to optimize a treatment design and minimize damage to healthy tissue.

40 / 44

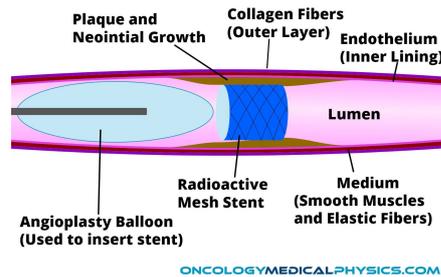


The physics of brachytherapy implants:

Treatment of atherosclerosis.

Research has also indicated that brachytherapy implants may have an important role to play in the treatment of atherosclerosis, in which blood vessels become blocked with plaque.

Intravascular Brachytherapy

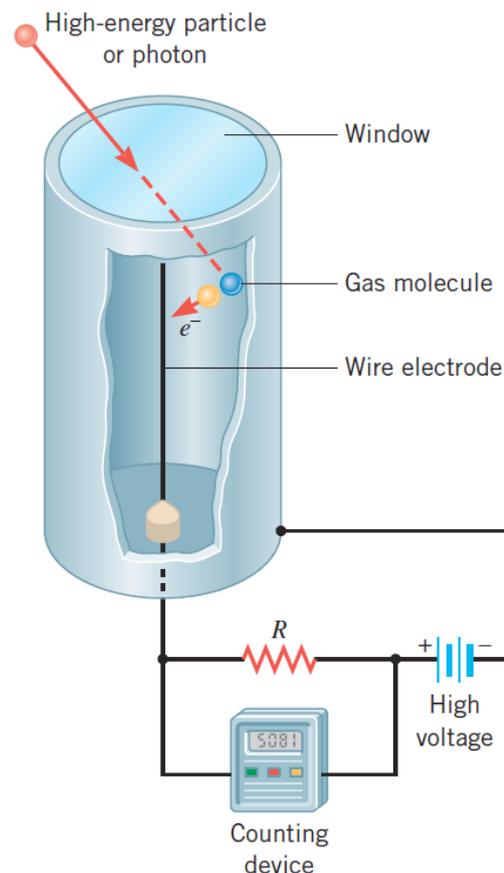


- Such blockages are often treated using the technique of balloon angioplasty. With the aid of a catheter inserted into an occluded coronary artery, a balloon is inflated to open the artery and place a stent (a metallic mesh that provides support for the arterial wall) at the site of the blockage.
- Sometimes the arterial wall is damaged in this process, and as it heals, the artery often becomes blocked again.
- Brachytherapy implants (using iridium $^{192}_{77}\text{Ir}$ or phosphorus $^{32}_{15}\text{P}$, for instance) have been found to inhibit repeat blockages following angioplasty.

41 / 44

Radiation detectors: Geiger counter

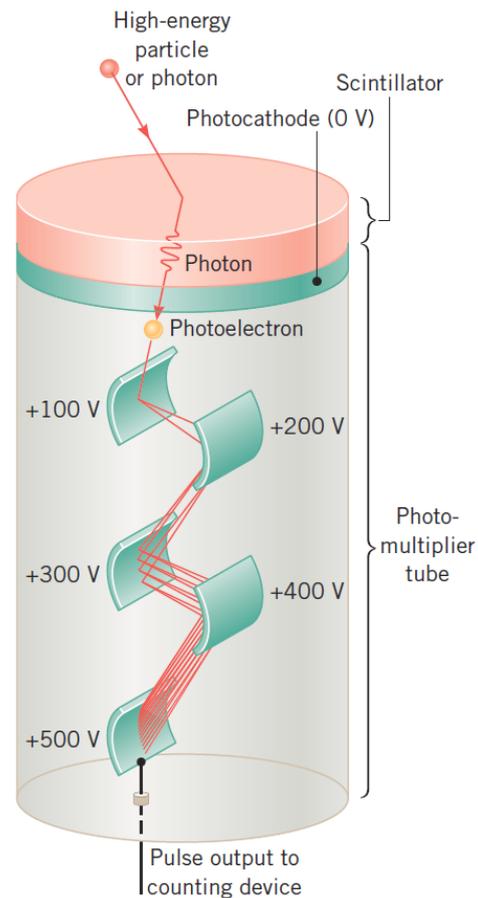
The counter consists of a tube filled with an inert gas that becomes conductive of electricity when it is impacted by a high-energy particle. When a Geiger counter is exposed to ionizing radiation, the particles penetrate the tube and collide with the gas, releasing more electrons.



42 / 44

Radiation detectors: scintillation counter

A NaI(Tl) "Thallium-doped sodium iodide" scintillation counter is a radiation detector which uses the effect known as scintillation. Scintillation, which occurs in the NaI(Tl) crystal, is a flash of light produced in a transparent material by the passage of a particle (an electron, an alpha particle, an ion, or a high-energy photon).



43 / 44

Homework Problems: Homework: 12, 13, 26, 45, 47

The End

44 / 44

Ionizing Radiation Measurement and its Biological Effects

- 1 Penetrating Power of Radiation
- 2 Units of Radiation Dose (Definitions)
- 3 Radiation Levels
- 4 Radiation Safety
- 5 Biological Effects of Radiation
- 6 Cellular Sensitivity to Radiation
- 7 Organ Sensitivity to Radiation
- 8 Radiation Risk
- 9 Justification of Medical Exposures
- 10 Radiation Doses to the Entire Body and Expected Effects

1 / 55

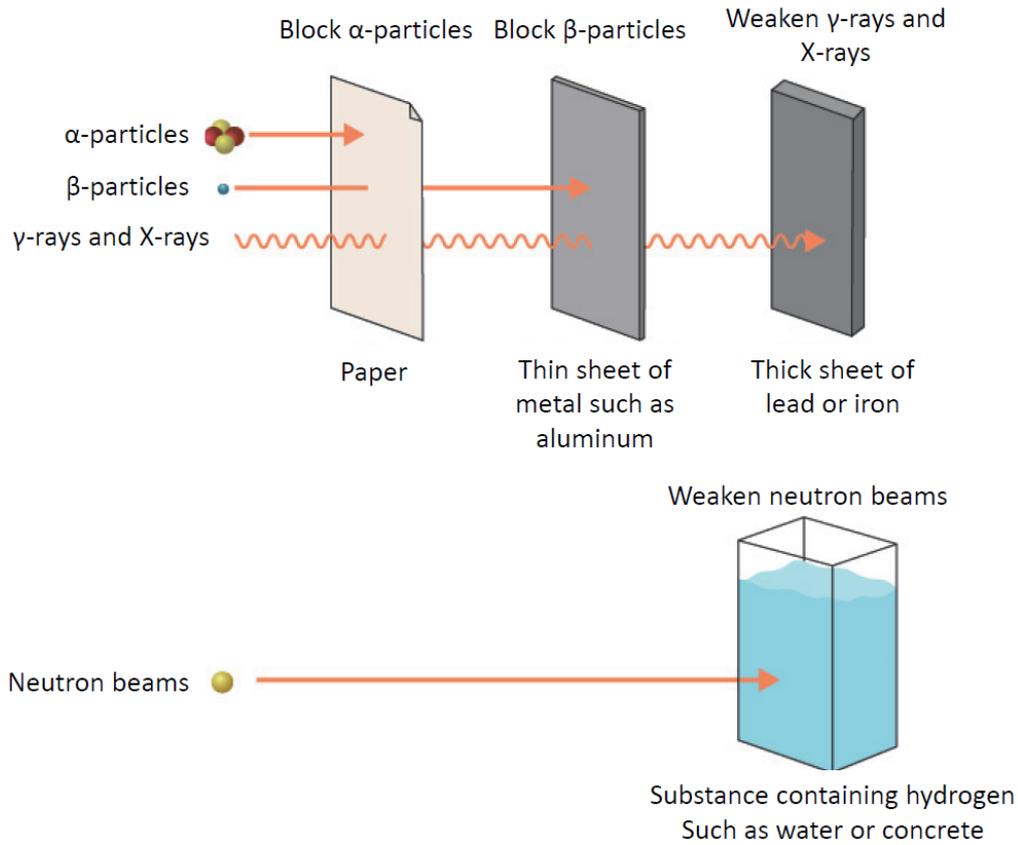
Material of this chapter is mainly from these agencies



2 / 55

Penetrating Power of Radiation

Radiation can be blocked by various substances.



Penetrating Power of Radiation within the Body

Distance traveling in the air

1 to 10 cm



Several meters

(depending on the amount of energy)



Several tens of meters

(depending on the amount of energy)



α -particles
 Particles (Helium nucleus)
 (One-trillionth of a centimeter)



β -particles
 Particles (electrons)



γ -rays
X-rays



Upon collision with the body

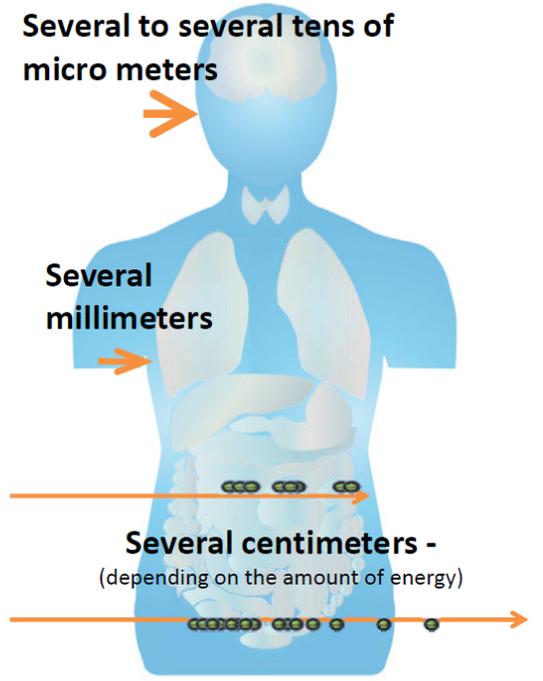
Several to several tens of micro meters



Several millimeters



Several centimeters -
 (depending on the amount of energy)



α -particles can travel only several centimeters in the air and a sheet of paper is enough to stop them. In the case of external exposure, α -particles do not reach deeper than the layer of dead cells (horny layer) on the skin surface and do not cause effects. However, if an alpha-emitting radionuclide enters the body, it will provide energy intensively to nearby cells where it is deposited.

Since β -particles travel only several meters in the air, they hardly contribute to exposure when a radiation source is located away from the body. When the surface of the body is exposed to β -particles, their energy is imparted to the skin and subcutaneous tissues; when β -particles enter the body, their energy is imparted to a radius of several millimeters around the relevant spot.

γ -rays and X-rays have high penetrating power and travel several tens to hundreds of meters in the air. When they collide with the human body, they can reach deep into the body or sometimes pass through it. Their energy is imparted to the part they pass through. In X-ray examination, the parts of the body X-rays can easily pass through (lungs, etc.) appear in black while the parts they cannot easily pass through (bones, etc.) appear in white.

5 / 55

Units of radiation dose (Definitions)

Measuring Radiation - Summary

There are four different but interrelated units for measuring radiation. These can be remembered by the mnemonic **R-E-A-D**, as follows, with both common (British, e.g., Ci) and international (metric, e.g., Bq) units in use:

Radioactivity

Exposure

Absorbed dose

Dose equivalent

6 / 55

Units of radiation dose (Definitions)

Radioactivity:

- Radioactivity refers to the amount of ionizing radiation released by a material.
- Radiation could be alpha or beta particles, gamma rays, x-rays, or neutrons.
- A quantity of radioactive material is expressed in terms of its radioactivity (or simply its activity), which represents how many atoms in the material decay in a given time period.

The unit of activity, R, is the curie (Ci)

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ decays/s}$$

The SI unit of activity is the becquerel (Bq)

$$1 \text{ Bq} = 1 \text{ decay/s}$$

$$\text{Therefore, } 1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$$



7 / 55

Units of radiation dose (Definitions)

Exposure:

- Exposure describes the amount of radiation traveling through the air.
- The units for exposure are the roentgen (R) and coulomb/kilogram (C/kg).
- Roentgen (R): A unit of exposure to ionizing radiation. It is the amount of gamma or x-rays required to produce ions resulting in a charge of 0.000258 coulombs/kilogram of air under standard conditions.
- The ICRU¹ recommended redefining the roentgen to be exactly $2.58 \times 10^{-4} \text{ C/kg}$ in 1971

¹International Commission on Radiation Units

Units of radiation dose (Definitions)

Absorbed dose: Absorbed dose describes the amount of radiation absorbed by an object or person (that is, the amount of energy that radioactive sources deposit in materials through which they pass).

The units for absorbed dose are the **radiation absorbed dose (rad)** and **gray (Gy)**.

$$1 \text{ (Gy)} = 1 \text{ Joules/kg}$$

$$1 \text{ (rad)} = 1/100 \text{ Gy}$$

9 / 55

Units of radiation dose (Definitions)

Dose equivalent: Dose equivalent (or biological equivalent dose) combines

- The amount of radiation absorbed
- And the medical effects of that type of radiation.

Units for dose equivalent are the **roentgen equivalent man (rem)** and **sievert (Sv)**, and biological dose equivalents are commonly measured in $\text{mrem} = 1/1000 \text{ rem}$.

Dose equivalent = $\text{RBE} \times \text{Absorbed dose}$

$$1 \text{ Sv} = 1 \text{ Gy} \times \text{RBE}$$

$$1 \text{ rem} = 1 \text{ rad} \times \text{RBE}$$

$$1 \text{ Sv} = 100 \text{ rem}$$

In radiobiology, the relative biological effectiveness (often abbreviated as RBE^2) is the ratio of biological effectiveness of one type of ionizing radiation relative to another, given the same amount of absorbed energy.

²Radiation weighting factor W_R

Units of radiation dose (Definitions)

Type and energy of radiation	RBE
X-rays	1
γ -rays	1
β rays for greater than 32 keV	1
β rays for less than 32 keV	1.7
Neutrons, thermal to slow(<20 keV)	2-5
Neutrons, fast (1-10 MeV)	10 (body), 32 (eyes)
Protons (1-10 MeV)	10 (body), 32 (eyes)
α rays from radioactive decay	10-20
α Heavy ions from accelerator	10-20

11 / 55

Units of radiation dose (Definitions)

Effective dose: It is the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the human body and represents the stochastic health risk to the whole body, which is the probability of cancer induction and genetic effects, of low levels of ionising radiation

Effective Dose = Equivalent Dose \times Effect of body part exposed (0-1)

Organ or tissue	W_T ICRP 30 (1979) ^a	W_T ICRP 60 (1991)	W_T ICRP 103 (2007)
Gonads	0.25	0.20	0.08
Red bone marrow	0.12	0.12	0.12
Large intestine		0.12	0.12
Lung	0.12	0.12	0.12
Stomach		0.12	0.12
Bladder		0.05	0.04
Breast	0.15	0.05	0.12
Liver		0.05	0.04
Oesophagus		0.05	0.04
Thyroid	0.03	0.05	0.04
Skin		0.01	0.01
Bone surface	0.03	0.01	0.01
Rest ^b	0.30	0.05	0.12
Brain			0.01
Total	1.00	1.00	1.00

^a ICRP 30 W_T are used to calculate EDE, whereas ICPR 60 W_T and ICRP 103 W_T give E values.

^b 'Rest' includes adrenals, small intestine, kidney, muscle, brain (except ICRP 103 W_T), pancreas, spleen, thymus and uterus.

12 / 55

$$\text{Effective dose (sievert (Sv))} = \Sigma (\text{Tissue weighting factor} \times \text{Equivalent dose})$$

When the whole body is evenly exposed to **1 mGy** of γ -ray irradiation

Effective dose =
 0.12×1 (mSv): bone marrow
 $+ 0.12 \times 1$ (mSv): colon
 $+ 0.12 \times 1$ (mSv): lungs
 $+ 0.12 \times 1$ (mSv): stomach
 :
 $+ 0.01 \times 1$ (mSv): skin
 = 1.00×1 (mSv)
= 1 millisievert (mSv)



When only the head is exposed to **1 mGy** of γ -ray irradiation

Effective dose =
 0.04×1 (mSv): thyroid
 $+ 0.01 \times 1$ (mSv): brain
 $+ 0.01 \times 1$ (mSv): salivary gland
 $+ 0.12 \times 1$ (mSv) $\times 0.1$: bone marrow (10%)
 $+ 0.01 \times 1$ (mSv) $\times 0.15$: skin (15%)
 :
= 0.07 millisieverts (mSv)

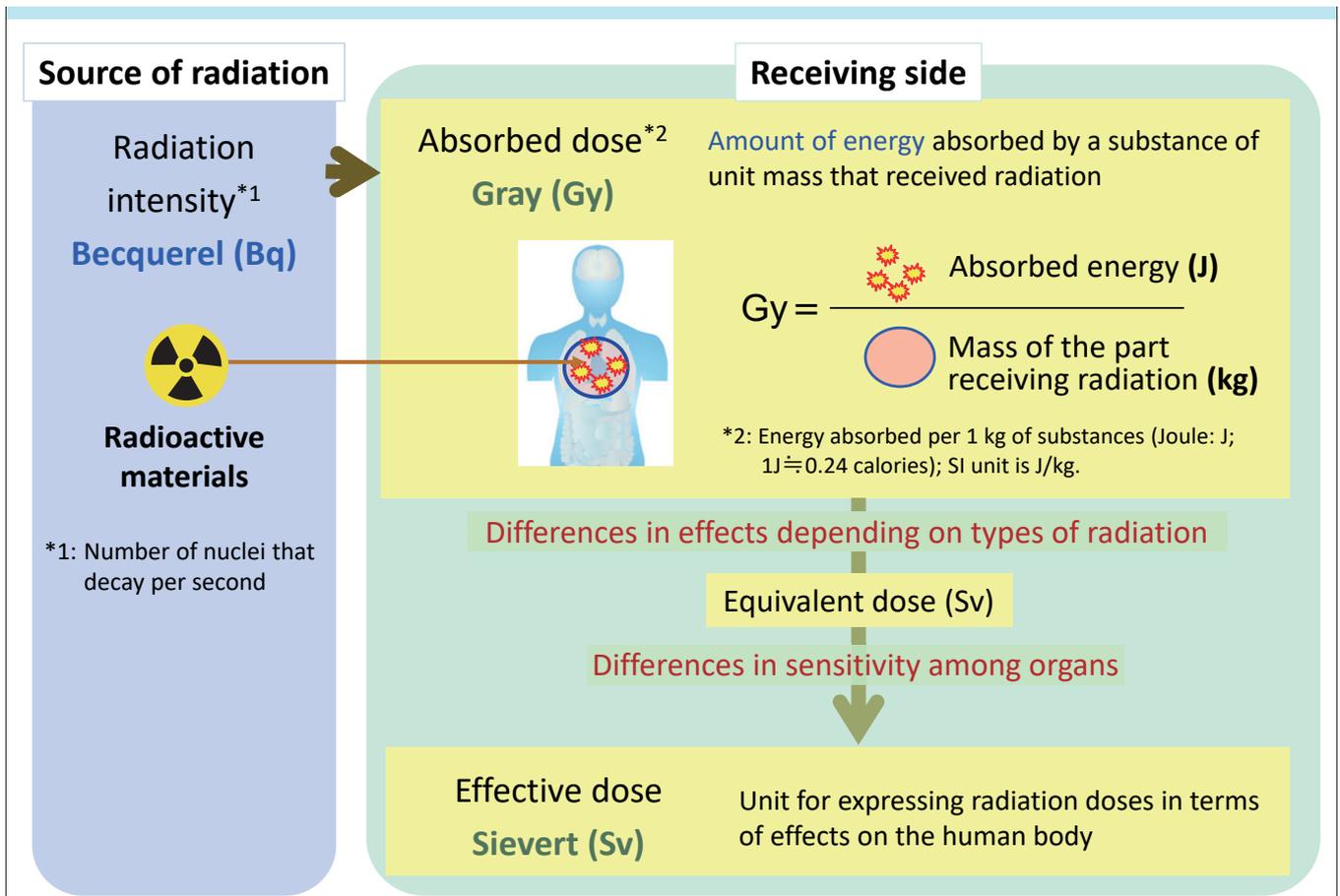


The health effects of one unit of dose to the entire body are more harmful than the same dose to only a portion of the body, e.g., the hand or the foot.

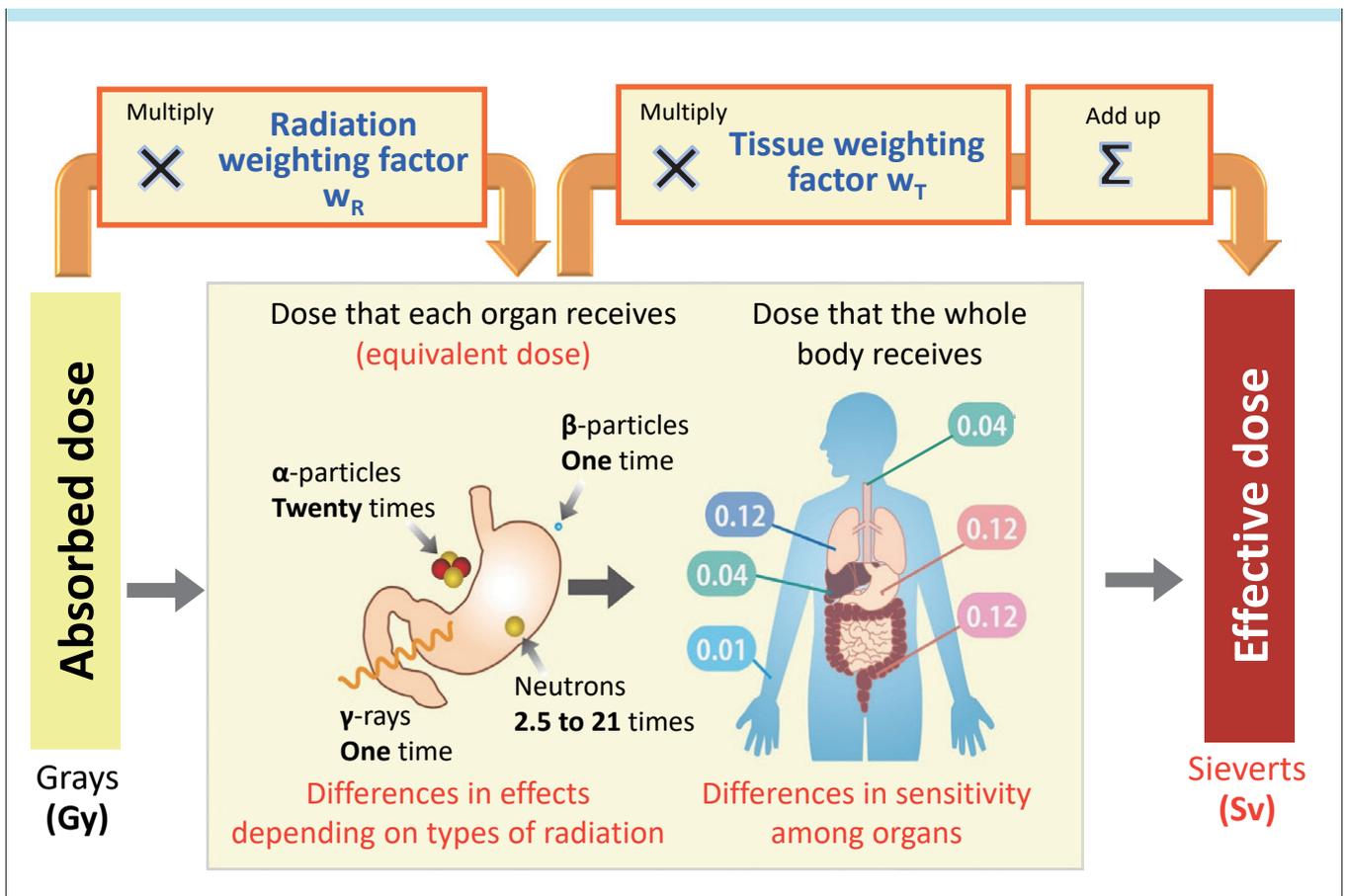
3 friends are discussing their radiation exposure and their future risk of cancer. They each have the same absorbed dose, but they know that the absorbed dose needs to be converted into effective dose to properly describe future biological risk. Each is convinced that their risk is the highest. They ask you to settle the dispute.

	ABSORBED DOSE	EQUIVALENT DOSE	EFFECTIVE DOSE
 Red guy was experimenting with radiation in his lab and accidentally exposed himself	500 mGy	$500 \text{ mGy} \times 3 (W_R) = 1500 \text{ mSv}$ The accident exposed red guy to protons, which have a radiation weighting factor of 2-5. We will use 3 for this example.	$1500 \text{ mSv} \times 1 (W_T) = 1500 \text{ mSv}$ Red guy's entire body was exposed, so the tissue weighting factor is 1
 Orange guy was exposed to radiation from a CT of the chest	500 mGy	$500 \text{ mGy} \times 1 (W_R) = 500 \text{ mSv}$ A CT of the chest exposed orange guy to x-rays, which have a radiation weighting factor of 1	$500 \text{ mSv} \times 0.014 (W_T) = 7 \text{ mSv}$ A CT of the chest includes some radiosensitive organs and has a combined tissue weighting factor of 0.014
 Yellow guy was exposed to radiation from a CT of the head	500 mGy	$500 \text{ mGy} \times 1 (W_R) = 500 \text{ mSv}$ A CT of the head exposed yellow guy to x-rays, which have a radiation weighting factor of 1	$500 \text{ mSv} \times 0.0021 (W_T) = 1.1 \text{ mSv}$ A CT of the head includes organs that are not very radiosensitive and has a combined tissue weighting factor of 0.0021

Radiation dose summary



Radiation dose summary



Radiation Levels

- Natural sources – rocks and soil, cosmic rays
 - ▶ Called background radiation
 - ▶ About 0.13 rem/yr (1.3 mSv/yr)
- Upper limit suggested by US government
 - ▶ 0.50 rem/yr (5 mSv/yr)
 - ▶ Excludes background
- Occupational
 - ▶ 5 rem/yr (50 mSv/yr) for whole-body radiation
 - ▶ Certain body parts can withstand higher levels
 - ▶ Ingestion or inhalation is most dangerous
- (Exception) Dose limits are not applied to medical exposure.
 - ▶ Justification on a case by case basis
 - ▶ Optimization of radiological protection is important.

50% mortality rate:

About 50% of the people exposed to a dose of 400 to 500 rem (4 to 5 Sv) will die

17 / 55

Example: Dose From Inhaled Plutonium I

Calculate the dose in rem/y for the lungs of a weapons plant employee who inhales and retains an activity of $1.00 \mu\text{Ci}$ of ^{239}Pu in an accident. The mass of affected lung tissue is 2.00 kg, the plutonium decays by emission of a 5.23-MeV α particle, assume the value of the RBE for α is 20.

Solution:

We to find the energy deposited in one year. Since the activity of the source is given, we can calculate the number of decays, multiply by the energy per decay, and convert MeV to joules to get the total energy.

$$\text{Activity } R = 1.0 \mu\text{Ci} = 3.7 \times 10^4 \text{ Decays/s}$$

So, the number of decays per year is obtained by multiplying by the number of seconds in a year:

$$3.7 \times 10^4 \text{ Decays/s} \times 3.16 \times 10^7 \text{ s/1year} = 1.17 \times 10^{12} \text{ decays}$$

Thus, the ionizing energy deposited per year is:

18 / 55

Example: Dose From Inhaled Plutonium II

$$1.17 \times 10^{12} \text{ decays} \times 5.23 \text{ MeV/decay} \times \frac{1.6 \times 10^{-13} \text{ J}}{1 \text{ MeV}} = 0.978 \text{ J}$$

Dividing by the mass of the affected tissue gives:

$$\text{Absorbed dose} = \frac{\text{Energy}}{\text{mass}} = \frac{0.978 \text{ J}}{2.0 \text{ kg}} = 0.489 \text{ J/kg (Gy)}$$

$$\text{Equivalent dose} = \text{Absorbed dose} \times \text{RBE} = (0.489)(20) = 9.8 \text{ Sv.}$$

By any standard, this yearly radiation dose is high and will have a devastating effect on the health of the worker. Worse yet, plutonium has a long radioactive half-life and is not readily eliminated by the body, and so it will remain in the lungs. Being an α emitter makes the effects 10 to 20 times worse than the same ionization produced by β s, γ rays, or x-rays.

19 / 55

Radiation dose: Example

The radioactive nuclei ^{131}I is widely used in medical applications. It undergoes beta decay, and the total energy of the decay process is 0.606 MeV per decay event. The half-life of this nucleus is 8.04 days. Suppose that a patient of mass 70 kg is given a dose of 30 mCi of ^{131}I . If 100% of this material decayed while in the patient's body, what is the equivalent dose? (1 Ci = 3.70×10^{10} decays/s, RBE=1)

20 / 55

Check Your Understanding 1

Two different types of radiation have the same RBE. Is it possible for these two types of radiation to deliver different biologically equivalent doses of radiation to a given tissue sample?

Check Your Understanding 2

The damage-producing character of a given type of ionizing radiation depends on (a) only the RBE of the radiation, (b) only the absorbed dose of the radiation, (c) both the RBE and the absorbed dose of the radiation

Check Your Understanding 3

A person faces the possibility of receiving the following absorbed doses of ionizing radiation: 20 rad of γ rays (RBE = 1), 5 rad of neutrons (RBE = 10), and 2 rad of α particles (RBE = 20). Rank the amount of biological damage that these possibilities will cause in decreasing order (greatest damage first).

21 / 55

Radiation Safety

- Current guidelines are based on the conservative assumption that there is no safe level of exposure.
- In other words, even the smallest exposure has some probability of causing a **stochastic effect**^{*}, such as cancer.
- This assumption has led to the general philosophy of not only keeping exposures below recommended levels or regulation limits but also maintaining all exposure "As Low As Reasonably Achievable"
ALARA.
- ALARA is a basic requirement of current radiation safety practices. It means that every reasonable effort must be made to keep the dose to workers and the public as far below the required limits as possible, and to avoid any unnecessary radiation exposure and to keep all exposures as low as reasonable achievable.

^{*}**Stochastic effect:** Effects that occur by chance, generally occurring without a threshold level of dose, whose probability is proportional to the dose and whose severity is independent of the dose. In the context of radiation protection, the main stochastic effects are cancer and genetic effects.

22 / 55

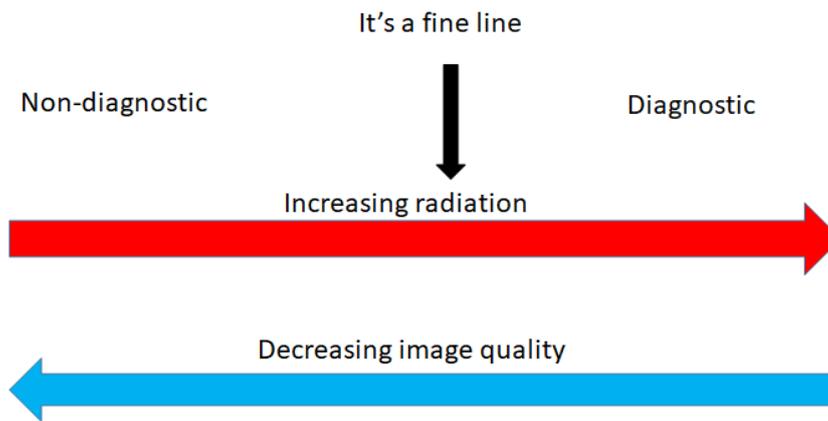
ALARA

And Diagnostic imaging:

This means use of the lowest dose of ionizing radiation that still results in diagnostic images



- If you reduce the radiation too much and the images are not good enough to make a diagnosis, the patient received a dose of radiation for nothing
- If you use a higher radiation dose than is needed to create diagnostic images, the patient received unnecessary radiation



23 / 55

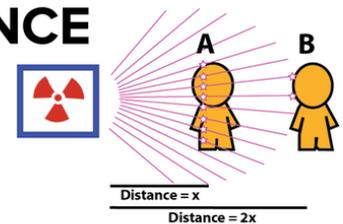
Radiation Safety: ALARA Principles

- Time refers to the length of exposure to radiation.
- Distance refers to the physical space between a person and the radiation source.
- Shielding refers to a material that can attenuate (decrease) the amount of ionizing radiation reaching a person.

TIME



DISTANCE



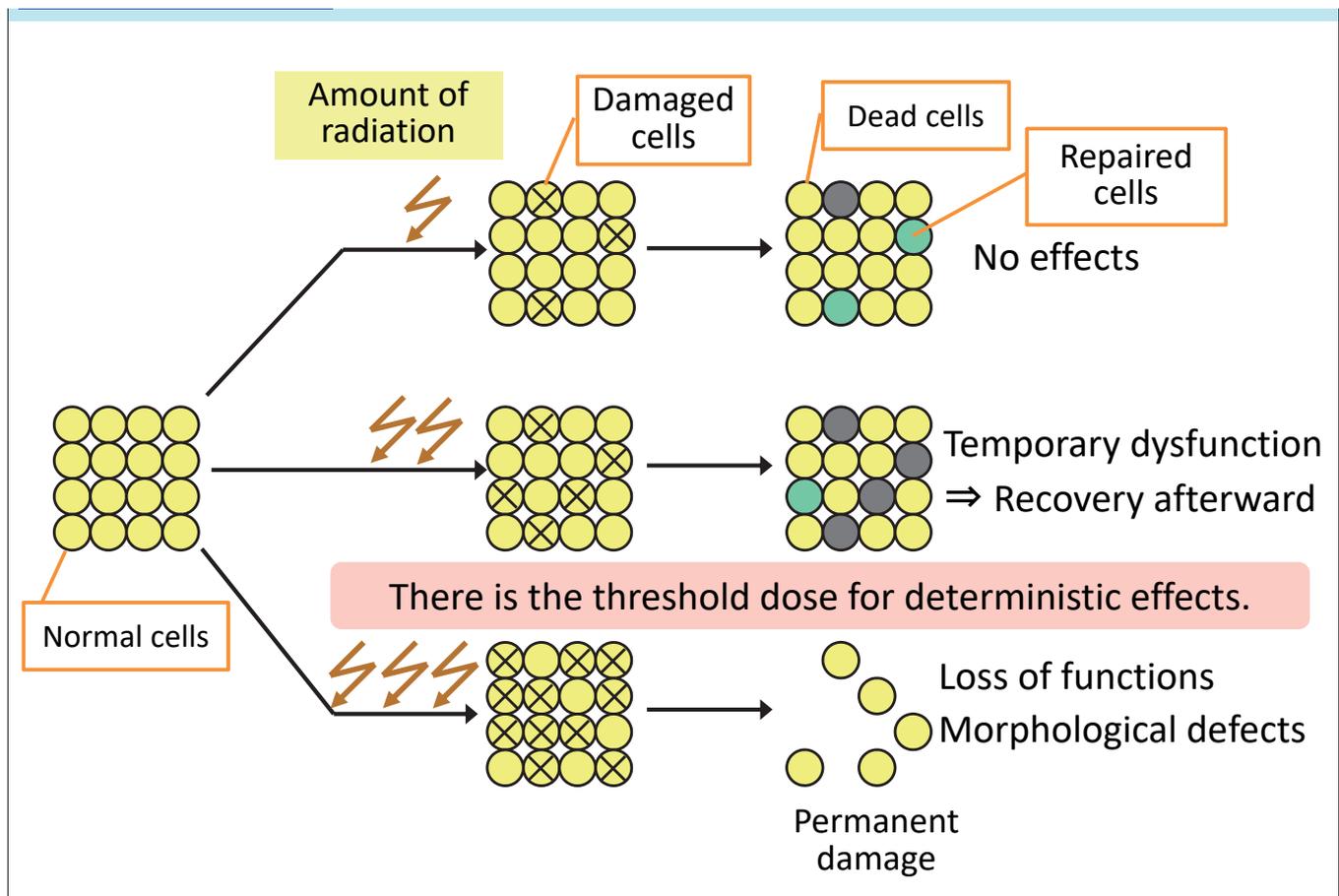
SHIELDING



As Low As Reasonably Achievable

24 / 55

Radiation Effects: Deterministic Effects



25 / 55

Deterministic Effects: Radiation Sickness

- Radiation sickness is damage to your body caused by a large dose of radiation often received over a short period of time (acute).
- The amount of radiation absorbed by the body — the absorbed dose — determines how sick you'll be.
- Radiation sickness is also called acute radiation syndrome or radiation poisoning.
- Radiation sickness is not caused by common imaging tests that use low-dose radiation, such as X-rays or CT scans.

26 / 55

Deterministic Effects

Threshold acute absorbed doses of γ -rays

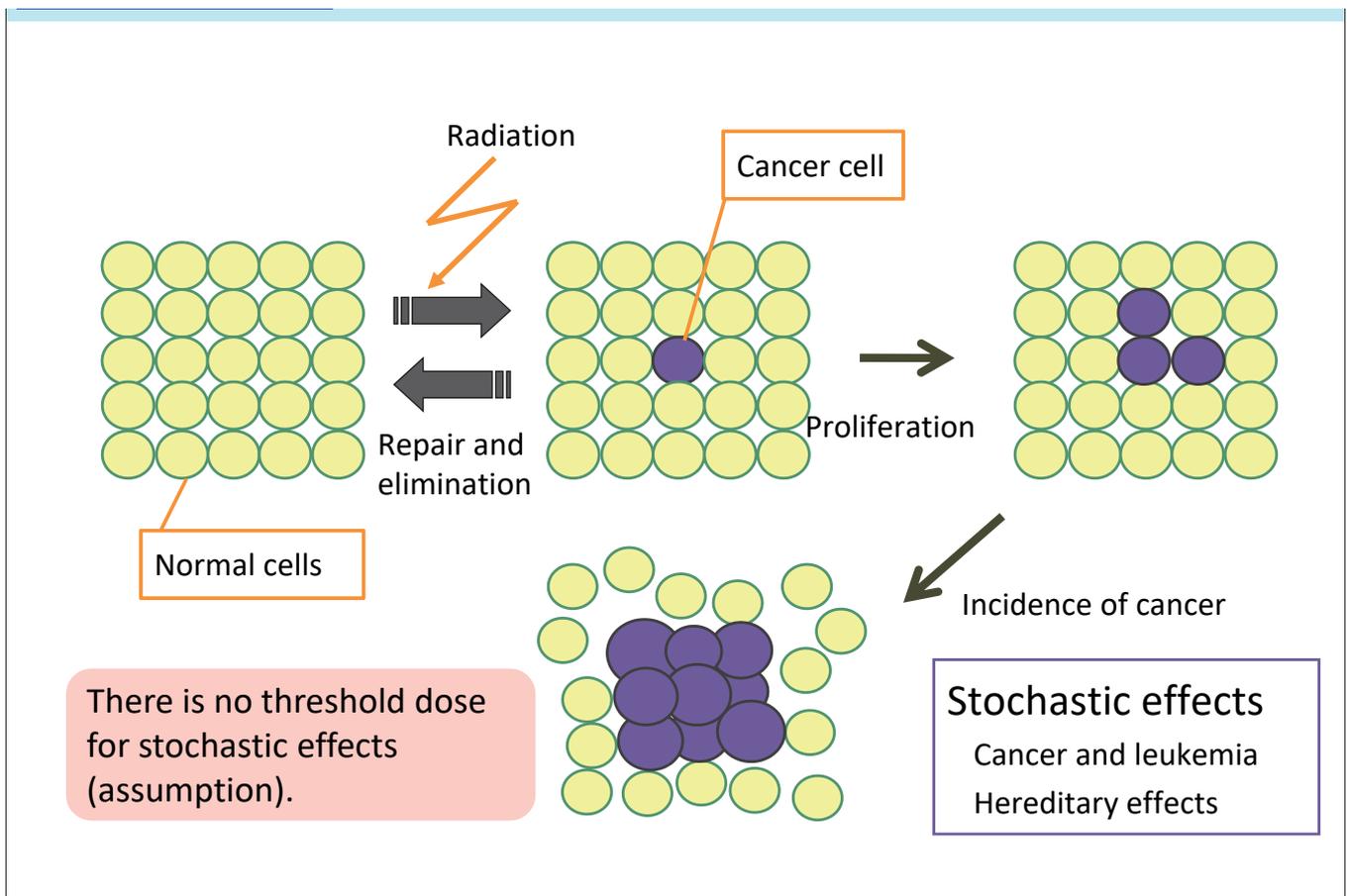
Disorders	Organs/Tissues	Incubation period	Threshold value (Gy)*
Temporary sterility	Testis	3 to 9 weeks	Approx. 0.1
Permanent sterility	Testis	3 weeks	Approx. 6
	Ovary	Within 1 week	Approx. 3
Deterioration of hemopoietic capacity	Bone marrow	3 to 7 days	Approx. 0.5
Skin rubor	Skin (large area)	1 to 4 weeks	3 to 6 or lower
Skin burn	Skin (large area)	2 to 3 weeks	5 to 10
Temporary hair loss	Skin	2 to 3 weeks	Approx. 4
Cataract (failing vision)	Eyes	20 years or longer	Approx. 0.5

* Threshold doses for symptoms with clear clinical abnormalities (doses causing effects on 1% of people)

Source: 2007 Recommendations of the International Commission on Radiological Protection (ICRP), and ICRP Report 118 (2012)

27 / 55

Stochastic Effects



28 / 55

Biological Effects of Radiation

Radiation Causes Ionizations of:

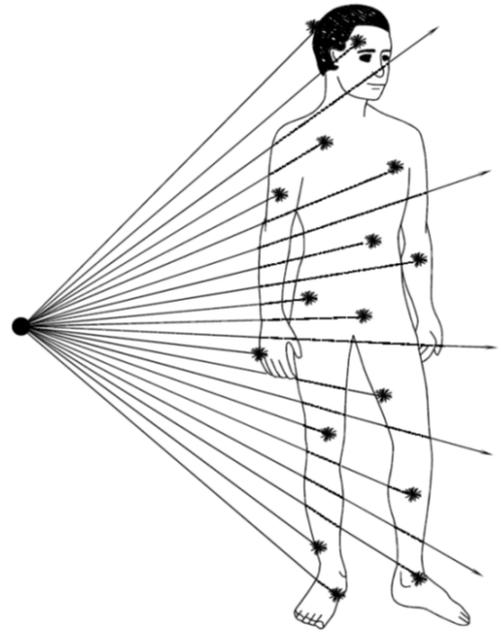
ATOMS

which may affect
MOLECULES

which may affect
CELLS

which may affect
ORGANS

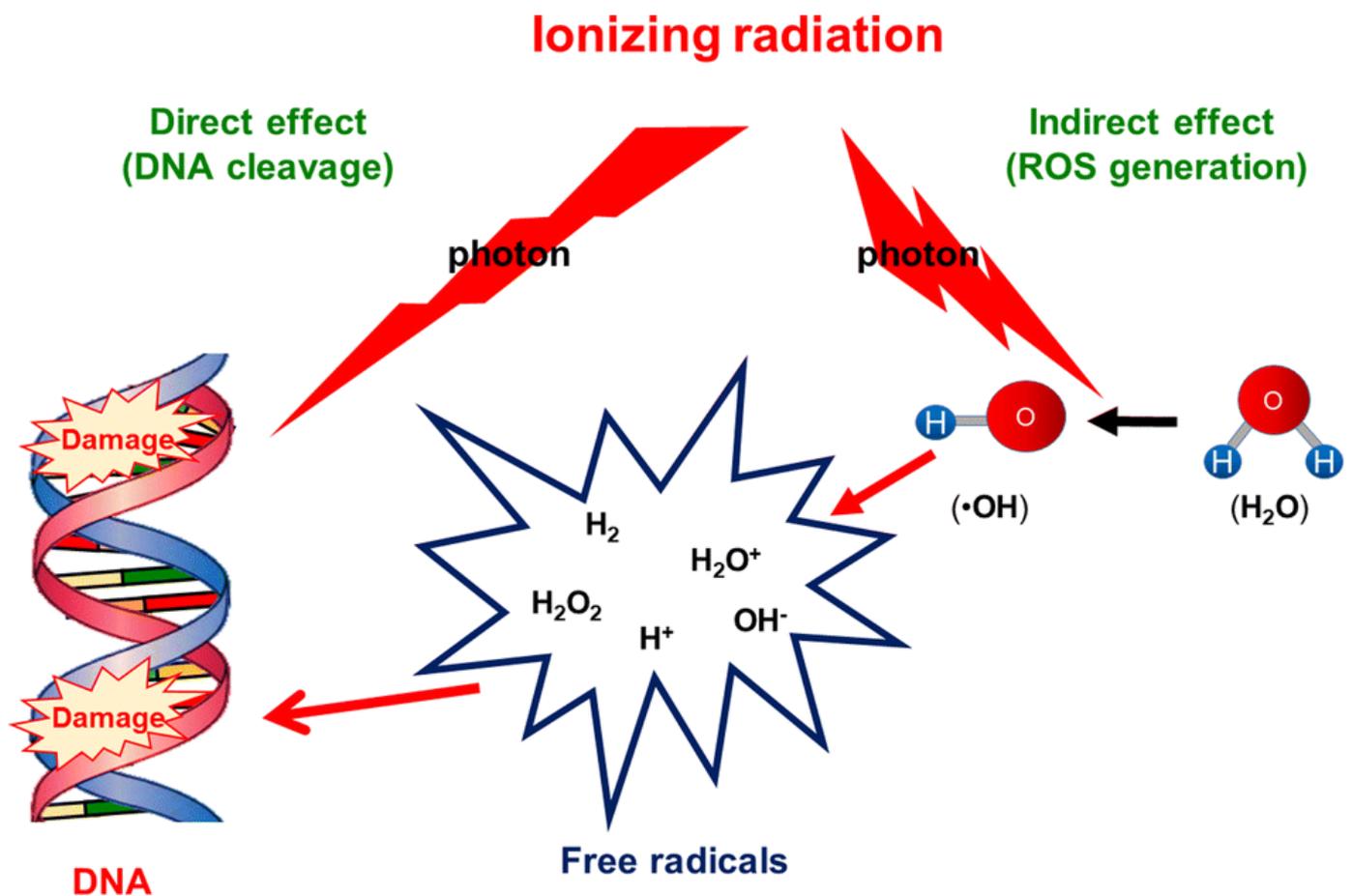
which may affect
THE WHOLE BODY



As a result, radiation effects on humans proceed from the lowest to the highest levels as noted in the list.

29 / 55

Biological Effects of Radiation: Cellular Damage



30 / 55

Cellular Damage: Direct Effect

- If radiation interacts with the atoms of the DNA molecule, or some other cellular component critical to the survival of the cell, it is referred to as a direct effect.
- Such an interaction may affect the ability of the cell to reproduce and, thus, survive.
- If enough atoms are affected such that the chromosomes do not replicate properly, or if there is significant alteration in the information carried by the DNA molecule, then the cell may be destroyed by “direct” interference with its life-sustaining system.

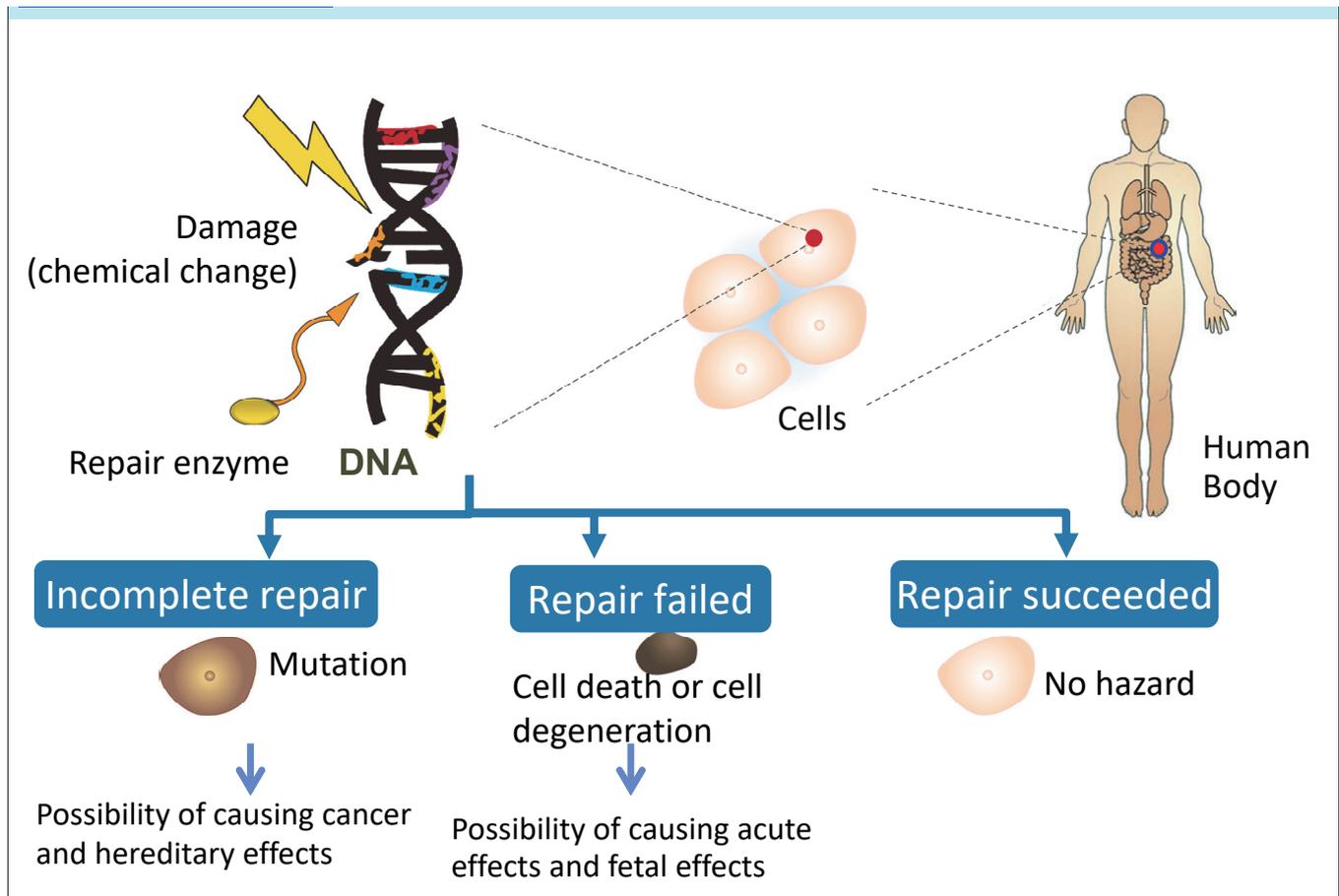
31 / 55

Cellular Damage: Indirect Effect

- In the indirect effect, there is a much higher probability of radiation interacting with the water that makes up most of the cell's volume.
- When radiation interacts with water, it may break the bonds that hold the water molecule together, producing fragments such as hydrogen (H^+) and hydroxyls (OH^-).
- These fragments may recombine or may interact with other fragments or ions to form compounds, such as water, which would not harm the cell. However, they could combine to form toxic substances, such as hydrogen peroxide (H_2O_2), which can contribute to the destruction of the cell.

32 / 55

Cellular Damage



33 / 55

Cellular Sensitivity to Radiation I

Cellular Sensitivity to Radiation

from most sensitive to least sensitive

Lymphocytes and Blood Forming Cells
Reproductive and Gastrointestinal (GI) Cells
Nerve and Muscle Cells

- Not all living cells are equally sensitive to radiation.
- Those cells which are actively reproducing are more sensitive than those which are not.
- This is because dividing cells require correct DNA information in order for the cell's offspring to survive.

34 / 55

Cellular Sensitivity to Radiation II

- A direct interaction of radiation with an active cell could result in the death or mutation of the cell, whereas a direct interaction with the DNA of a dormant cell would have less of an effect.
- As a result, living cells can be classified according to their rate of reproduction, which also indicates their relative sensitivity to radiation.

This means that different cell systems have different sensitivities.

- Lymphocytes (white blood cells) and cells which produce blood are constantly regenerating, and are, therefore, the most sensitive.
- Reproductive and gastrointestinal cells are not regenerating as quickly and are less sensitive.
- The nerve and muscle cells are the slowest to regenerate and are the least sensitive cells.

35 / 55

Organ Sensitivity to Radiation

from most sensitive to least sensitive

Blood Forming Organs

Reproductive and Gastrointestinal Tract Organs

Skin

Muscle and Brain

- The sensitivity of the various organs of the human body correlate with the relative sensitivity of the cells from which they are composed.
- For example, since the blood forming cells were one of the most sensitive cells due to their rapid regeneration rate, the blood forming organs are one of the most sensitive organs to radiation.
- Muscle and nerve cells were relatively insensitive to radiation, and therefore, so are the muscles and the brain.

36 / 55

Sensitivity I

Sensitivity Rate of Reproduction Oxygen Supply

- A very sensitive cell system is a malignant tumor. The outer layer of cells reproduces rapidly, and also has a good supply of blood and oxygen.
- Cells are most sensitive when they are reproducing, and the presence of oxygen increases sensitivity to radiation.
- Anoxic cells (cells with insufficient oxygen) tend to be inactive, such as the cells located in the interior of a tumor.
- As the tumor is exposed to radiation, the outer layer of rapidly dividing cells is destroyed, causing it to “shrink” in size.

37 / 55

Sensitivity II

- If the tumor is given a massive dose to destroy it completely, the patient might die as well.
- Instead, the tumor is given a small dose each day, which gives the healthy tissue a chance to recover from any damage while gradually shrinking the highly sensitive tumor.
- Another cell system that is composed of rapidly dividing cells with a good blood supply and lots of oxygen is the developing embryo. Therefore, the sensitivity of the developing embryo to radiation exposure is similar to that of the tumor, however, the consequences are dramatically different.

38 / 55

Radiation Risk:

The term "risk" generally means "dangerousness" or "degree of hazard." However, more strictly, the term is used to refer to:

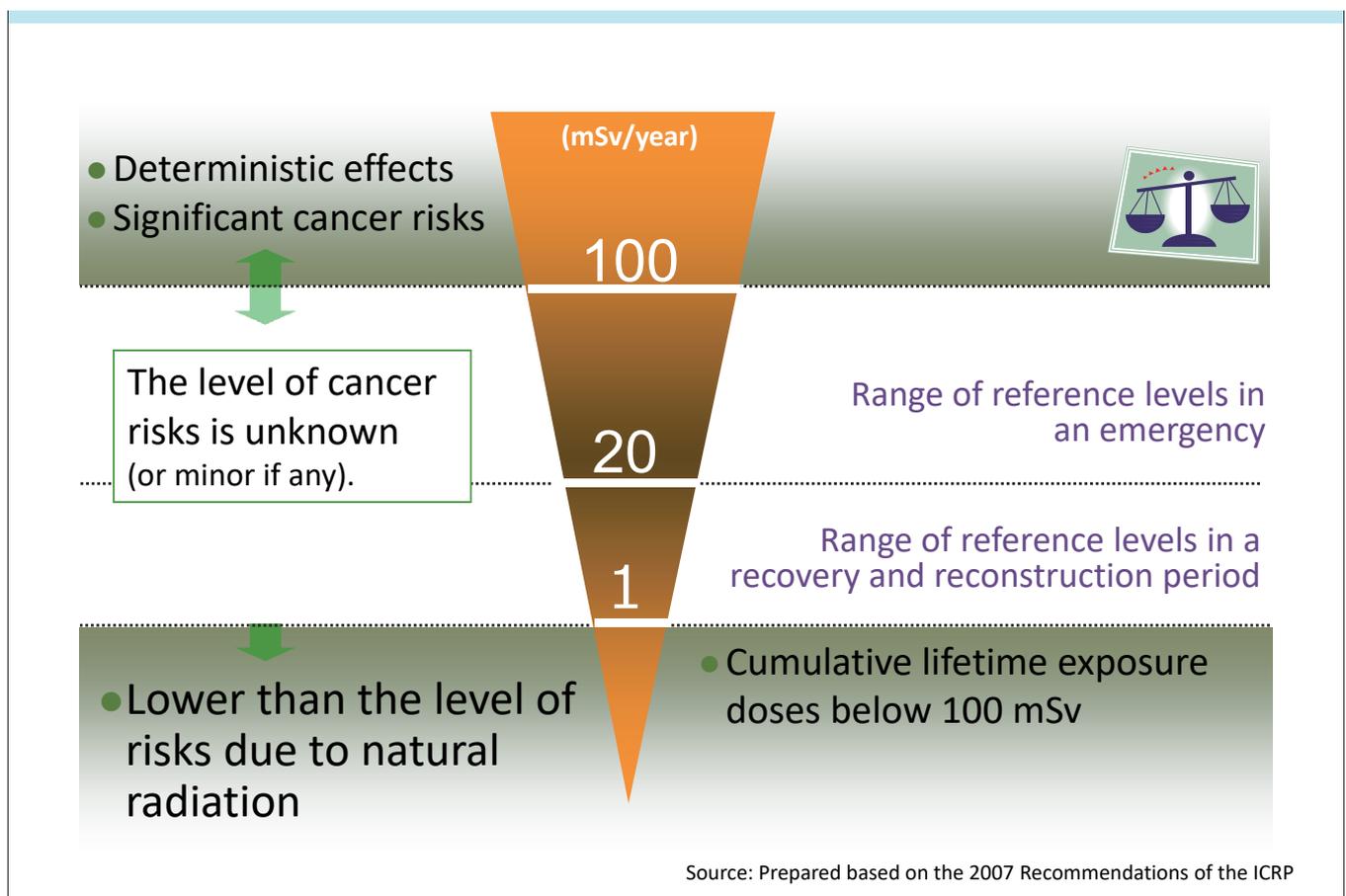
- the magnitude of the influence of damage
- the possibility of any damage (probability)
- or the combination of the magnitude of the influence and the possibility (probability).

When considering health effects of radiation, in particular, **stochastic effects** of radiation

It is common to use the term "risk" in the sense of "the probability (of contracting cancer or dying of cancer)."
In this case, it should be noted that "having risks" is not equal to "(surely) being subject to damage."

39 / 55

Radiation Risk:



40 / 55

Radiation Risk: Risks of cancer

Radiation doses (mSv)	Relative risk of cancer*
1000 - 2000	1.8 (estimated to be 1.5 times per 1000 mSv)
500-1000	1.4
200-500	1.19
100-200	1.08
Less than 100	Difficult to detect

Risks of developing radiation-induced cancer are based on the data (solid cancers only) obtained from the analysis of instantaneous exposure due to the atomic bombing in Hiroshima and Nagasaki, and are not based on the observation of long-term exposure effects.

* Relative risks indicate how many times larger the cancer risks are among people exposed to radiation when assuming the risks among non exposed people as 1.

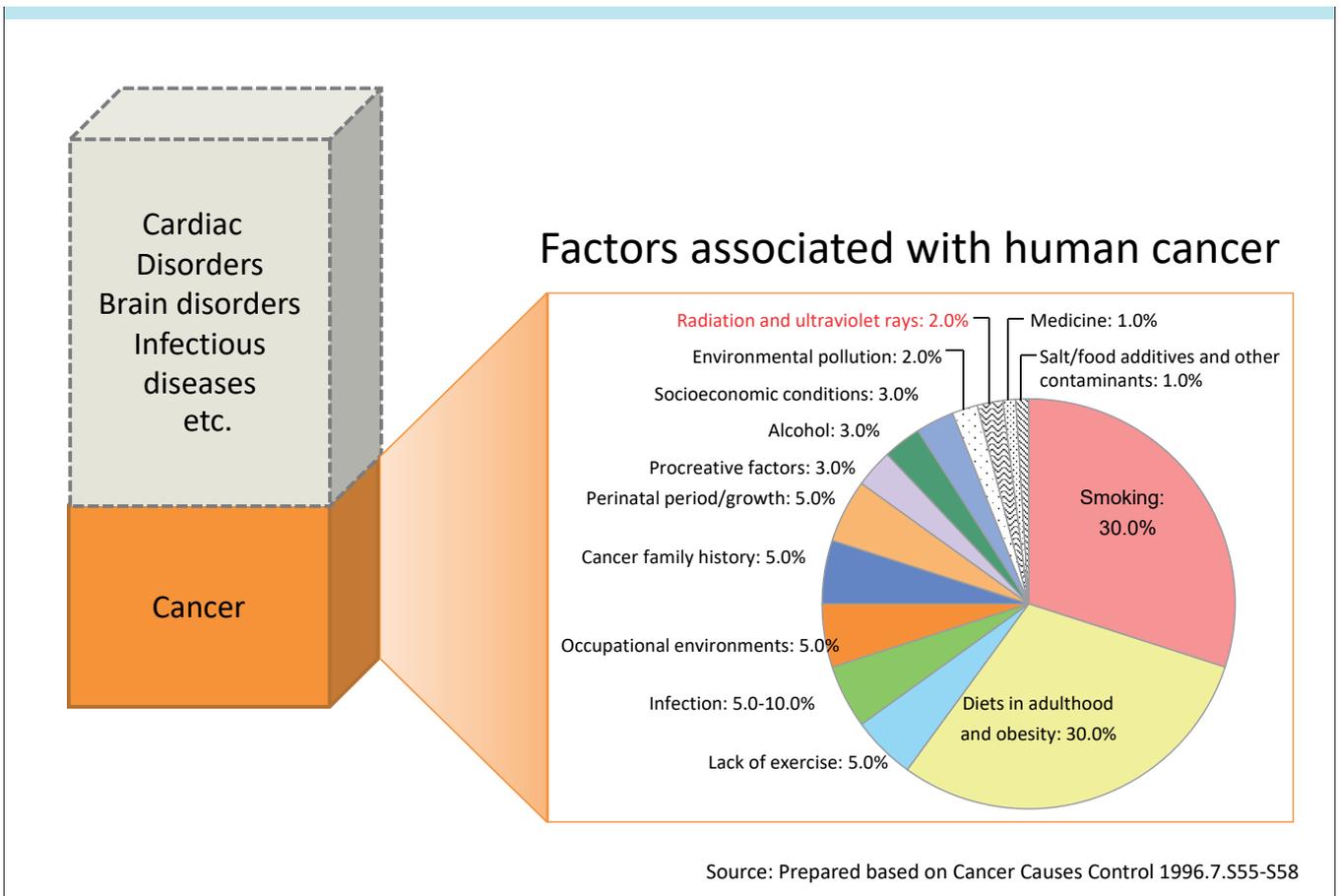
41 / 55

Risks of Cancer (Life Habits)

Lifestyle factors	Relative risk of cancer
Smokers	1.6
Heavy drinking	1.6
Obese (BMI \geq 30)	1.22
Underweight (BMI $<$ 19)	1.29
Lack of exercise	1.15-1.19
High salt food	1.11-1.15
Lack of vegetable intake	1.06
Passive smoking(nonsmoking females)	1.02-1.03

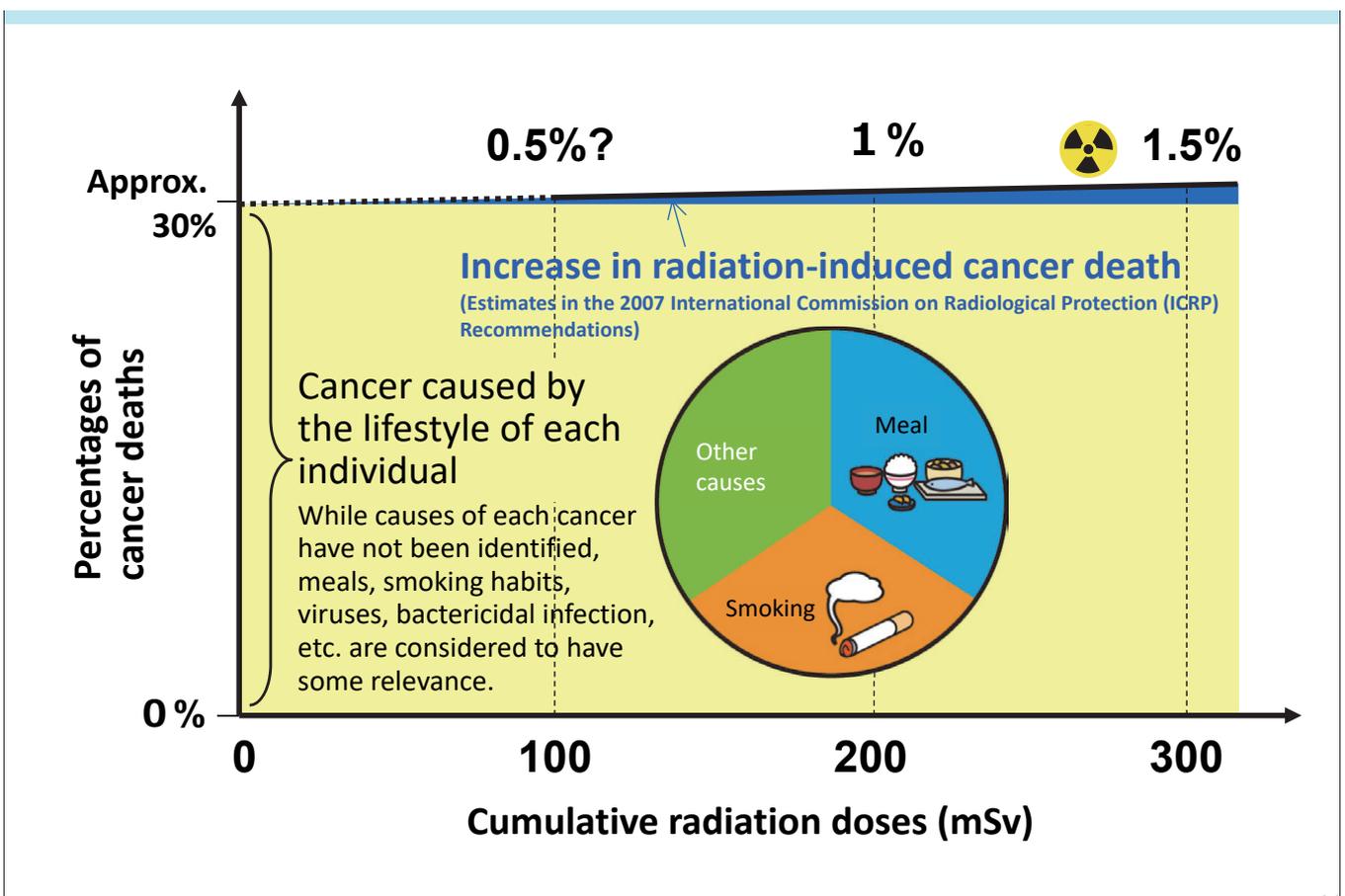
42 / 55

Factors Associated with Carcinogenesis



Risks of Cancer Death from Low-Dose Exposure

Estimated risk of low-dose exposure based on data obtained from atomic bomb survivors.

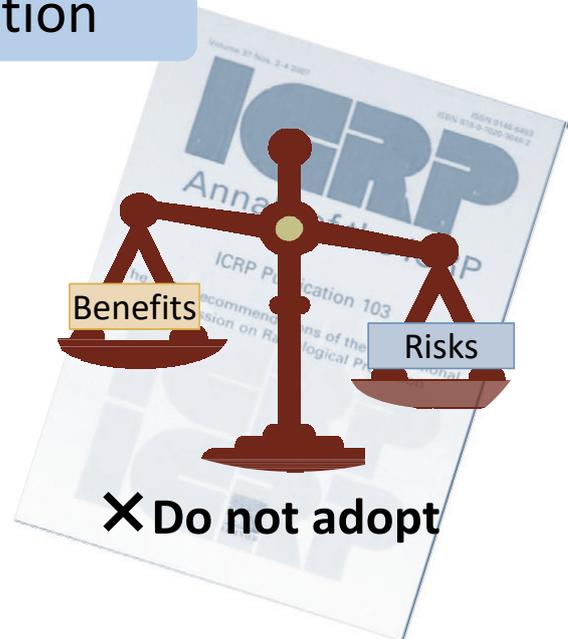


Justification of Radiological Protection

Justification



○ Adopt



✗ Do not adopt

Source: ICRP Publication 103, "The 2007 Recommendations of the International Commission on Radiological Protection" (ICRP, 2007)

45 / 55

Justification of Medical Exposures³

- A medical procedure involving radiation should be done only when there is a question to be answered is something broken, why the pounding headaches, could there be cancer?
- This is justification; i.e., there should be an appropriate medical reason for the x-ray to be performed.
- The issue of medical radiation exposure is not only a matter of safety; it's a matter of benefit compared with risk.
- For properly performed common medical radiation procedures that are necessary in light of the patient's medical condition, safety alone is not the issue.

³ICRP Publication 60; Ann ICRP 21(1-3); 1991

46 / 55

Radiation Doses to the Entire Body and Expected Effects

50-200 mSv Possible late effects; possible chromosomal damage.

200-1000 mSv Temporary reduction in white blood cells.

1-2 Sv Mild radiation sickness within a few hours: vomiting, diarrhea, fatigue; reduction in resistance to infection.

2-3 Sv Serious radiation sickness effects as in 1-2 Sv and hemorrhage; exposure is a Lethal Dose to 10-35% of the population after 30 days (LD 10-35/30).

3-4 Sv Serious radiation sickness; also marrow and intestine destruction; LD 50-70/30.

4-10 Sv Acute illness, early death; LD 60-95/30.

10-50 Sv Acute illness, early death in days; LD 100/10.

What is the LD 50 30 For humans?

The dose of radiation expected to cause death to 50 percent of an exposed population within 30 days (LD 50/30). Typically, the LD 50/30 is in the range from 400 to 450 rem (4 to 5 sieverts) received over a very short period.

47 / 55

Radiation Doses to the Entire Body and Expected Effects



This man was exposed accidentally to 17 Sv of Gamma radiation

48 / 55

Question

Ionizing radiation can be harmful to living things because of which of the following reasons?

- A Cells may be destroyed by the thermal energy released by radioactive decay.
- B Cells may be damaged by nuclear fusion occurring within them.
- C Cells may be damaged by nuclear fission occurring within them.
- D Cells may be damaged by fast moving helium nuclei, electrons, or very high frequency photons.
- E Cells may be damaged by the beta decay of .

49 / 55

Question

What is the absorbed dose of fast neutrons ($RBE = 9.5$) that is biologically equivalent to 75 rad of slow neutrons ($RBE = 2.0$)?

- A 350 rad
- B 120 rad
- C 16 rad
- D 48 rad
- E 5.0 rad

50 / 55



Problem 1

Neutrons ($RBE = 2.0$) and α particles have the same biologically equivalent dose. However, the absorbed dose of the neutrons is six times the absorbed dose of the α particles. What is the RBE for the α particles?

51 / 55



Problem 2

What absorbed dose (in rads) of α particles ($RBE = 15$) causes as much biological damage as a 60-rad dose of protons ($RBE = 10$)?

52 / 55

 **Problem 3**

Over a full course of treatment, two different tumors are to receive the same absorbed dose of therapeutic radiation. The smaller of the tumors (mass = 0.12 kg) absorbs a total of 1.7 J of energy. (a) Determine the absorbed dose, in Gy. (b) What is the total energy absorbed by the larger of the tumors (mass = 0.15 kg)?

53 / 55

 **Problem 5**

A beam of particles is directed at a 0.015-kg tumor. There are 1.6×10^{10} particles per second reaching the tumor, and the energy of each particle is 4.0 MeV. The RBE for the radiation is 14. Find the biologically equivalent dose given to the tumor in 25 s.

54 / 55



Problem 9

A 2.0-kg tumor is being irradiated by a radioactive source. The tumor receives an absorbed dose of 12 Gy in a time of 850 s. Each disintegration of the radioactive source produces a particle that enters the tumor and delivers an energy of 0.40 MeV. What is the activity $\Delta N/\Delta t$ of the radioactive source?