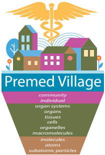

Physics Notes

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Physics

MECHANICS

- Kinematics
- Newton's Laws
- Work, Energy, and Power
- Harmonic Motion
- Elastic Properties of Solids
- Fluid Mechanics

WAVES

- Waves

GRAVITATION

- Gravitation

THERMODYNAMICS

- Heat & Temperature
- The Ideal Gas and Kinetic Theory
- The First Law of Thermodynamics
- The Second Law of Thermodynamics and Heat Engines

ELECTRICITY & MAGNETISM

- Electricity
- DC Current
- Magnetism

LIGHT & OPTICS

- The Properties of Light
- Geometric Optics
- Wave Optics

MODERN PHYSICS & NUCLEAR PHYSICS

- Modern Physics
- Nuclear Physics

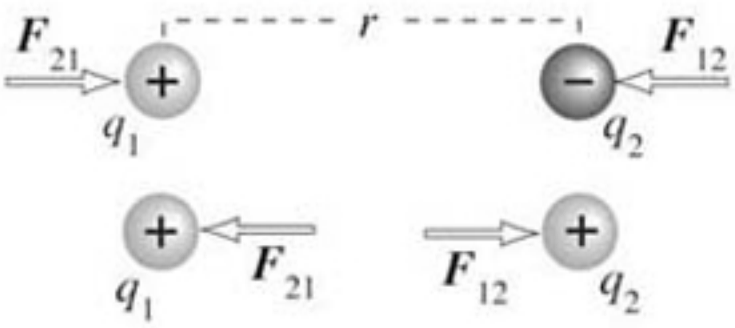
- Kinematics ✓
- Newton's Laws ✓
- Work, Energy, & Power ✓
- Electricity ✓
- Ideal Gas & Kinetic Theory
- Atomic Theory
- Periodic Properties
- The Chemical Bond
- Intermolecular Forces
- Organic Functional Groups
- Stereochemistry

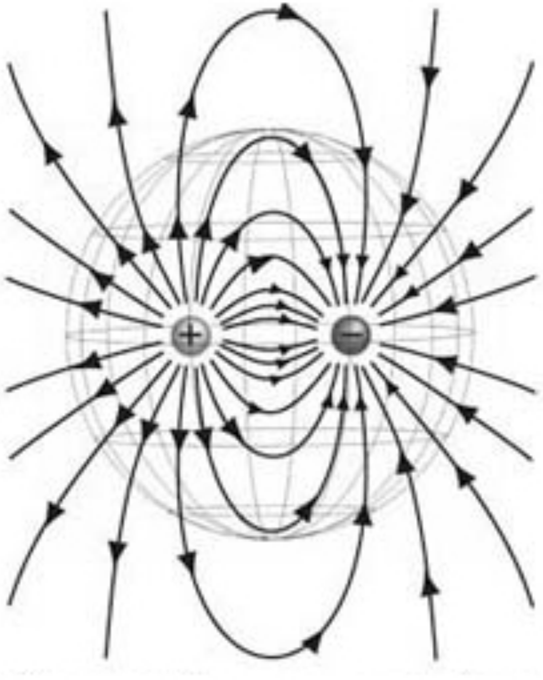
- Temperature & Heat Flow
- 1st Law of Thermodynamics
- Stoichiometry
- Thermochemistry
- 2nd Law & Heat Engines
- Chemical Thermodynamics & Equilibrium
- The States of Matter
- Organic Physical Properties
- Solutions
- Acids & Bases
- Organic Reaction Mechanisms
- Amino Acids & Protein Structure

Biochemistry

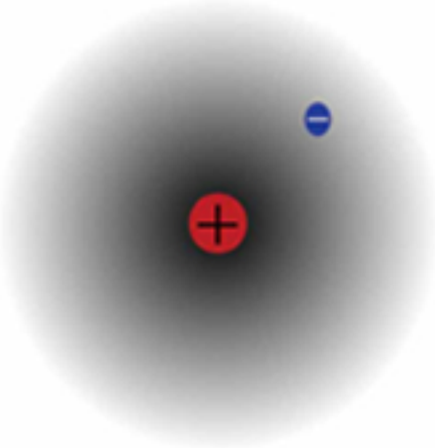
- Fluid Mechanics
- Deformations, Oscillations & Vibrations
- Waves

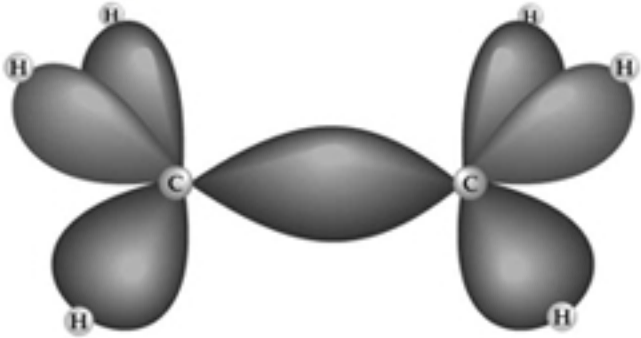
Physics

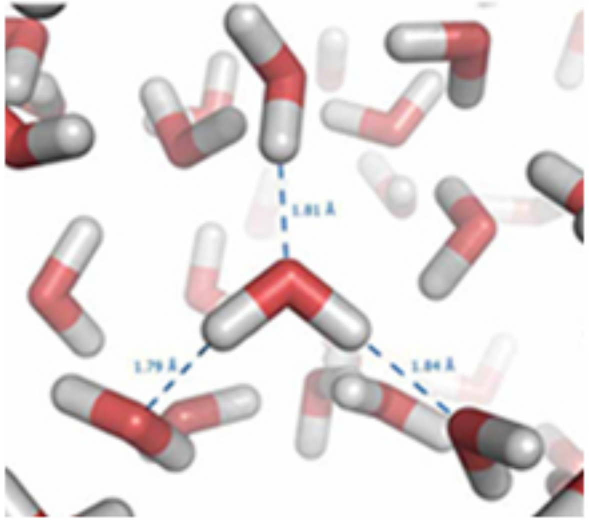




Chemistry







KINEMATICS • How things move

Displacement Δx (m)

vectors and scalars

Velocity (m/s)

speed is the magnitude of the velocity

Acceleration (m/s^2)

'meters per second per second'

Displacement, Velocity and Acceleration

$$\bar{v} = \frac{x - x_0}{\Delta t}$$

$x - x_0 = \Delta x$

$\Delta x = \bar{v} \Delta t$

$$\bar{a} = \frac{v - v_0}{\Delta t}$$

$\Delta v = \bar{a} \Delta t$

The Kinematics of Constant Acceleration

$$v = v_0 + at$$

$$x - x_0 = \tfrac{1}{2}(v + v_0)t$$

$$x - x_0 = v_0 t + \tfrac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

Motion in Two Dimensions

$$a_r = \frac{v^2}{r}$$

Uniform Circular Motion

Projectile Motion

$$v_y = v_{y_0} - gt$$

$$v_x = v_{x_0} = \text{constant}$$

Four Equations of Kinematics for Constant Acceleration

$$v = v_0 + at$$

$\Delta v = at$

$$x - x_0 = \frac{1}{2}(v + v_0)t$$

$\Delta x = \bar{v} t$

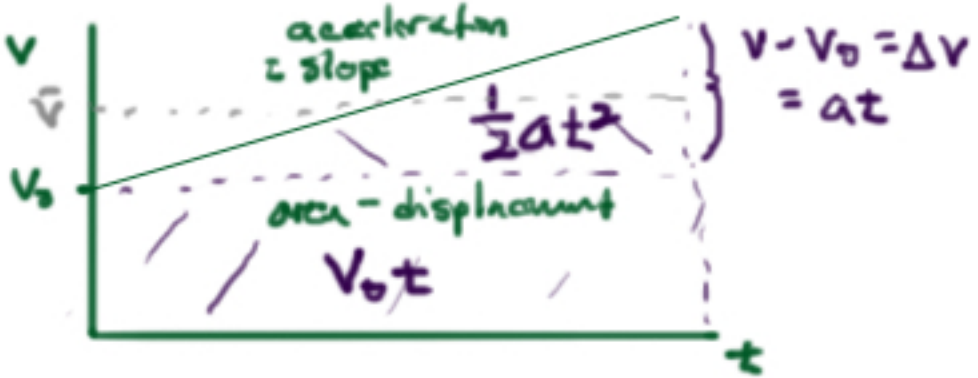
$$v^2 = v_0^2 + 2a(x - x_0)$$

$v^2 - v_0^2 = 2a\,\Delta x$

$\frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 = ma\,\Delta x = F\Delta x$ (work)

$\Delta KE = \text{work}$

$$x - x_0 = v_0 t + \frac{1}{2}at^2 \quad *$$



mass (kg)

Force ($kg \cdot m/s^2 = N$)

DYNAMICS

Newton's Laws of Motion

$\Sigma F = 0$ then $a = 0$ $F = ma$ $F_{12} = -F_{21}$

Free Body Diagrams

Static equilibrium - when there's no net force and no net torque

Friction Force

$F_s \leq \mu_s N$ ← threshold of static friction

$F_k = \mu_k N$

The Fundamental Forces

$$F = G\frac{m_1 m_2}{r^2}$$

Gravitation

$$F = k\frac{q_1 q_2}{r^2}$$

$$F = qBv\sin\theta$$

Electromagnetism

WORK, ENERGY, AND POWER

Work 1 N·m = 1 J
(energy)

Power · 1 J/s = 1 Watt

Work

$$W = (F\cos\theta)s$$

Work = force · distance
↑
parallel to displacement

Kinetic Energy

$$K = \frac{1}{2}mv^2$$

Potential Energy

$$U = mgh$$

$$U_{spr} = \frac{1}{2}kx^2$$

↑
mass spring

$$U_e = k\frac{q_1 q_2}{r}$$

↑
2 point charges

Conservation of Energy

$$K_i + U_i = K_f + U_f$$

Power

$$\bar{P} = \frac{\Delta W}{\Delta t}$$

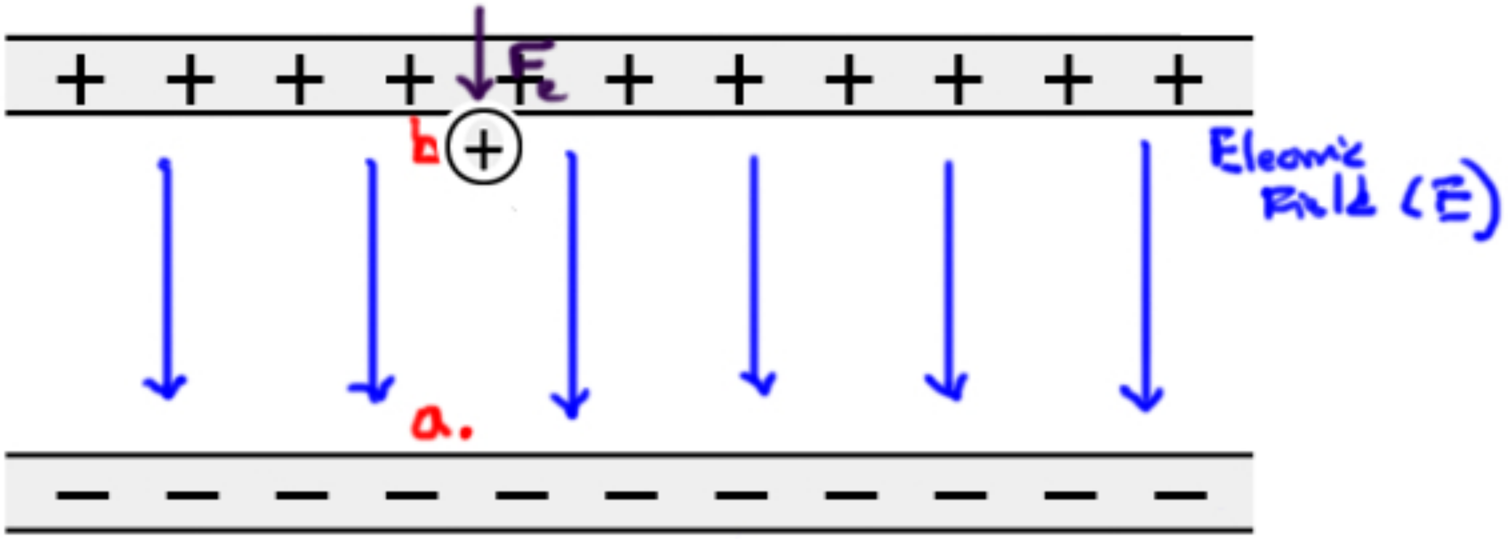
$$P = Fv$$

Electric, q
charge
- Coulombs
(C)

Electric Field, E
N/C

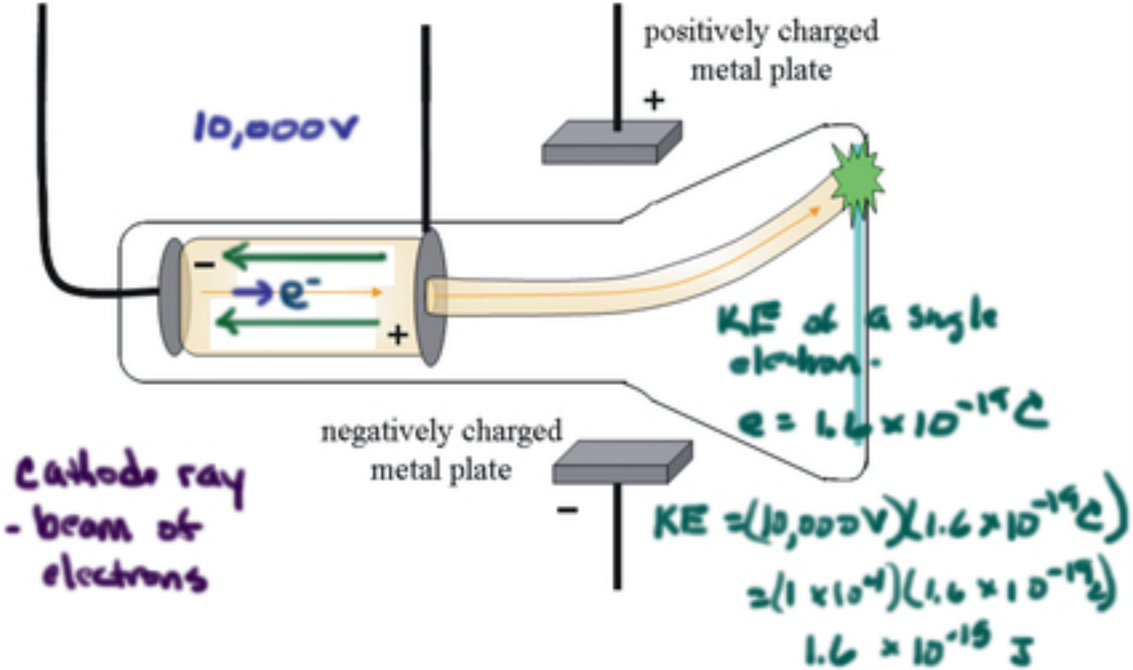
Potential Difference
V, voltage
Volt - J/C

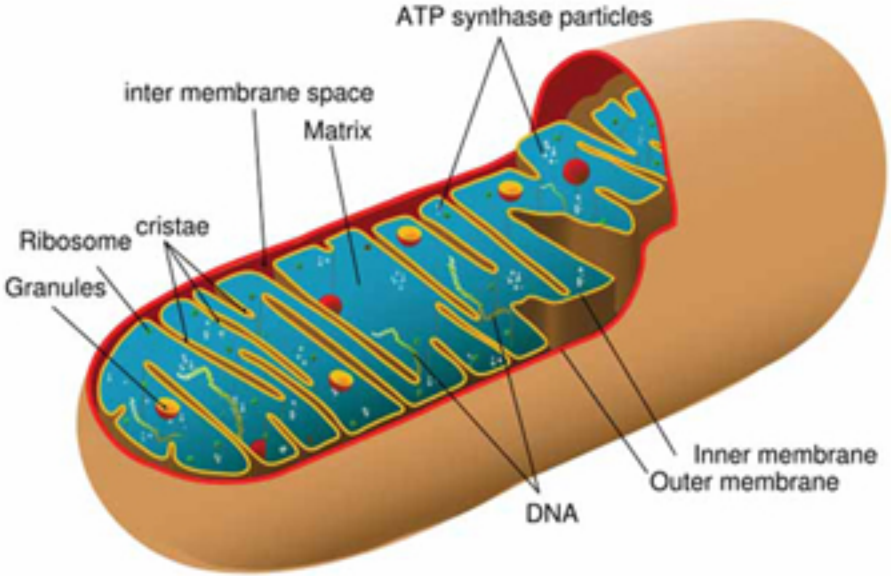
uniform electric field

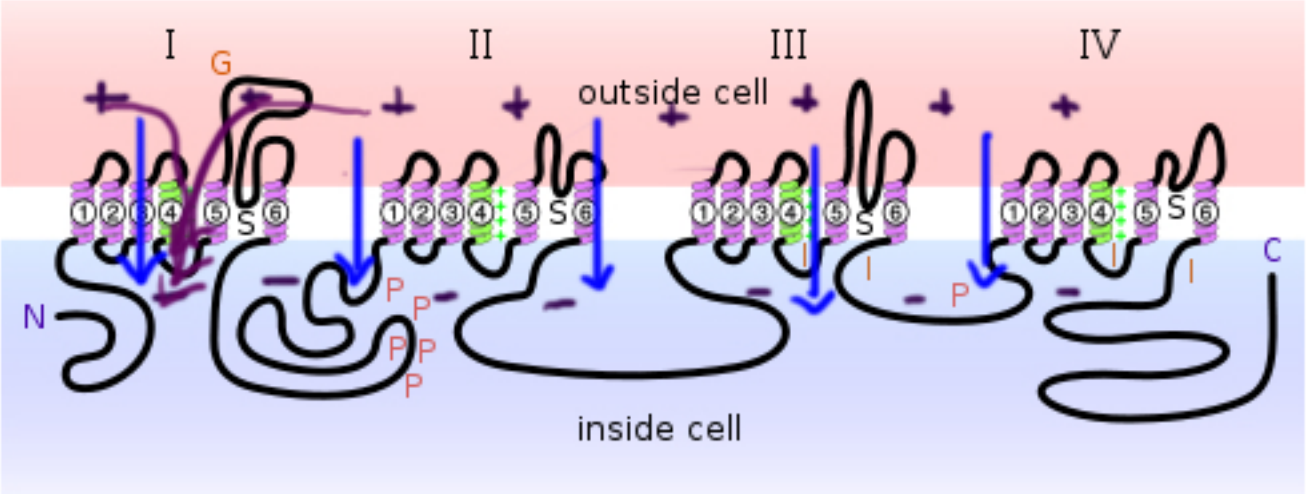


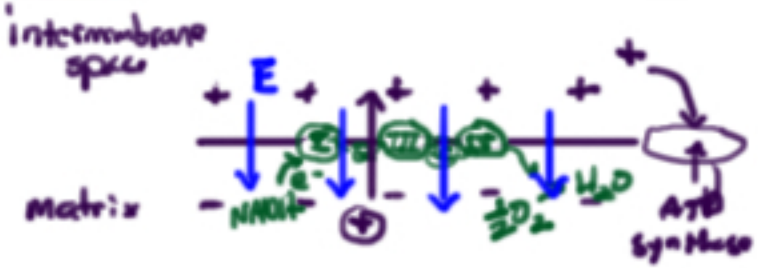
Kinematics	Dynamics	Work & Energy
constant acceleration	$F = Eq$	$V = Ed$
	$F = ma$	1 volt = J/c

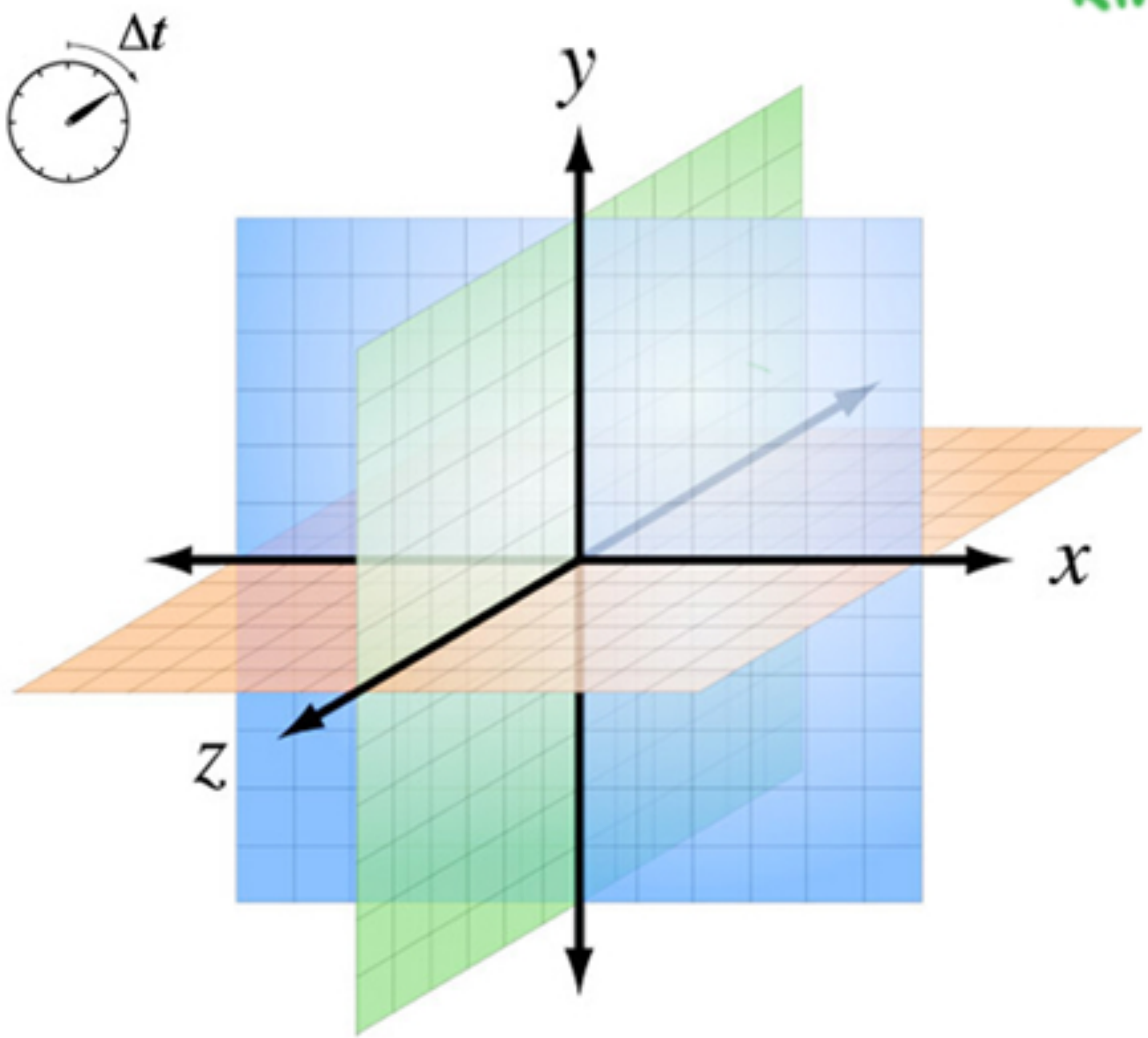
work = force · distance


positively charged metal plate
+
10,000V
-
e-
+
negatively charged metal plate
-
Cathode ray
- beam of electrons
KE of a single electron
$e = 1.6 \times 10^{-19} C$
$KE = (10,000V)(1.6 \times 10^{-19} C)$
$= (1 \times 10^{4})(1.6 \times 10^{-19})$
$1.6 \times 10^{-15} J$

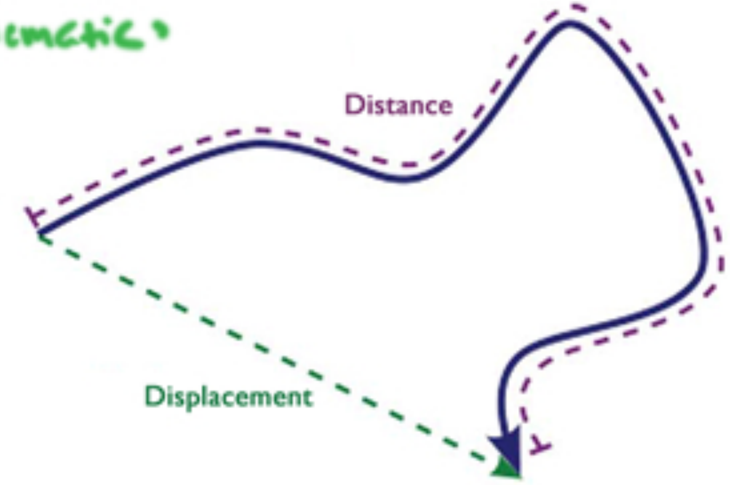

ATP synthase particles
inter membrane space
Matrix
Ribosome
cristae
Granules
Inner membrane
Outer membrane
DNA


I
G
II
III
IV
outside cell
N
C
inside cell


intermembrane space
E
Matrix
NADH
H_2O
ATP synthase



Kinematics



- displacement Δx
- velocity $\frac{\Delta x}{\Delta t} = \bar{v}$
- acceleration $\frac{\Delta v}{\Delta t} = \bar{a}$

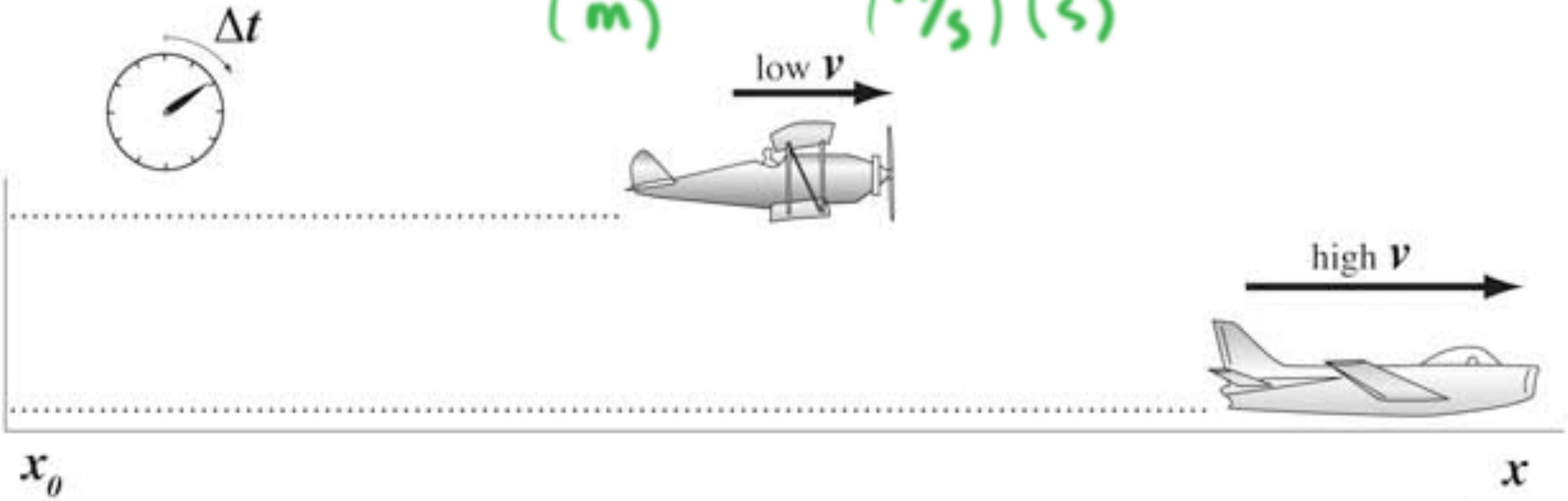
Velocity

$$\bar{v} = \frac{x - x_0}{\Delta t}$$

$\bar{v}$	=	average velocity
$x - x_0$	=	change in position
Δt	=	change in time

$$x - x_0 = \bar{v}\,\Delta t$$

(m) (m/s) (s)



Acceleration

$$\bar{a} = \frac{v - v_0}{\Delta t}$$

$\bar{a}$ = average acceleration

$v - v_0$ = change in velocity

Δt = change in time

$$v - v_0 = \bar{a}\,\Delta t$$

$$(m/s) = (m/s^2)(s)$$

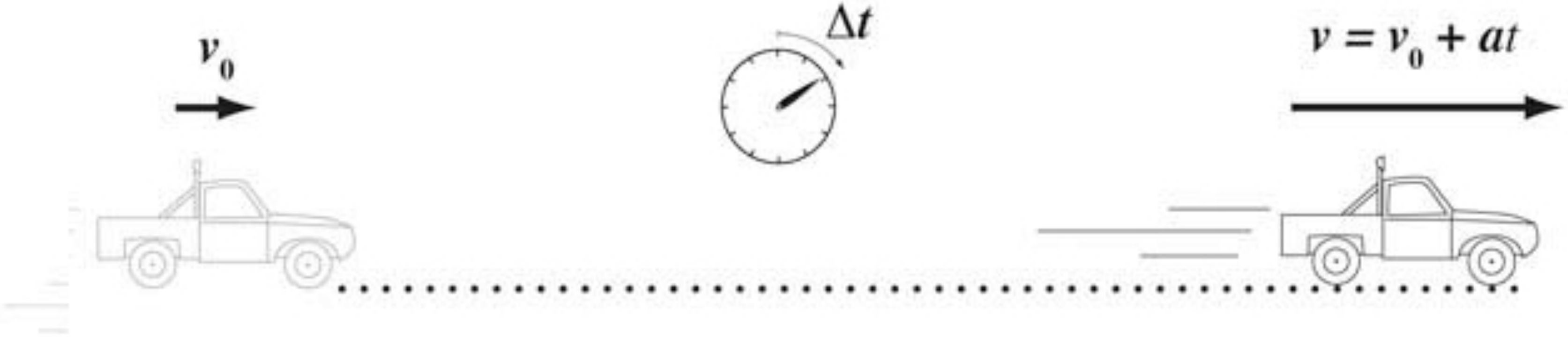
Velocity as a Function of Time

constant acceleration

$$v = v_0 + at$$

$\Delta v = at$

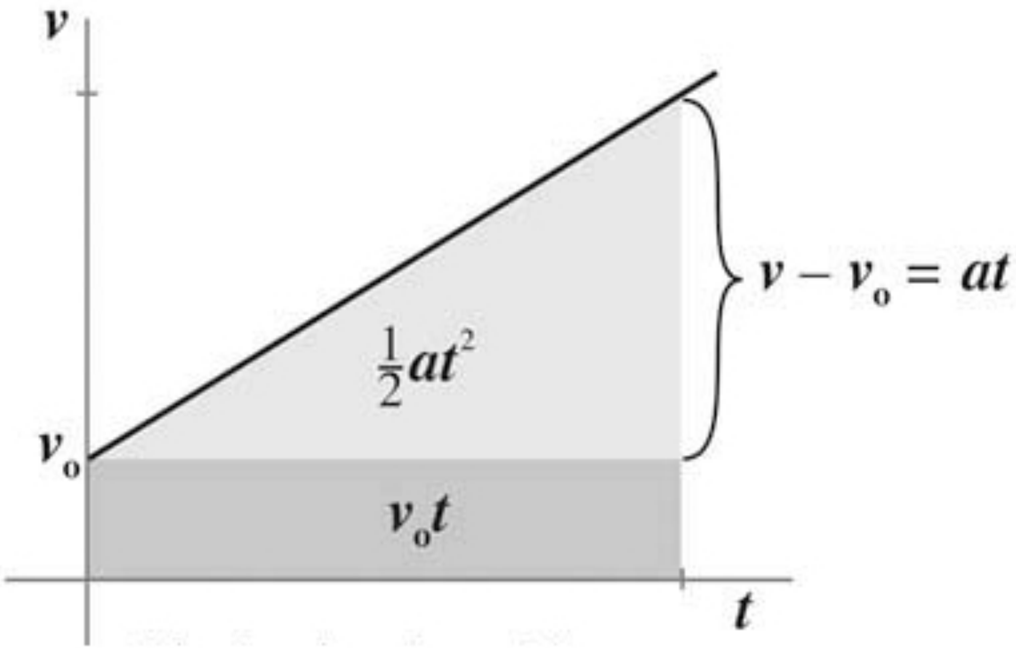
v = velocity
v_0 = initial velocity
a = acceleration (constant)
t = time



Displacement Equation

$$x - x_0 = v_0 t + \frac{1}{2}at^2$$

x-x_0 = change in position
v_0 = initial velocity
t = change in time
a = acceleration (constant)



The tallest apple tree in the world is 12 meters tall.

Approximately how long would it take an apple falling from the highest branch to hit the ground?

$\Delta x = 12\,m$

$v_0 = 0$

$a = 10\,m/s^2$

$\Delta x = v_0 t + \frac{1}{2} a t^2$

$12\,m = \frac{1}{2}(10\,m/s^2)(t^2)$

$t^2 = 12/5\ s^2$

$t^2 = 2.4$

$t = 1.5\,s$

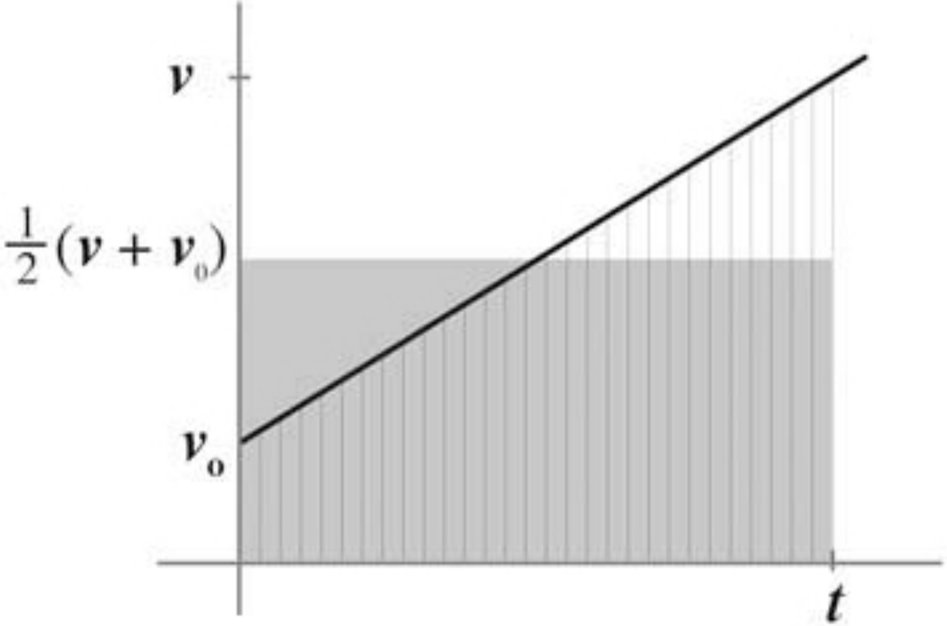
Displacement is the Product of Average Velocity and Time

$$x - x_0 = \frac{1}{2}(v + v_0)t$$

constant acceleration

x-x_0 = change in position
v = velocity
v_0 = initial velocity
t = change in time

$$\Delta x = \bar{v} t$$



Velocity as a Function of Displacement

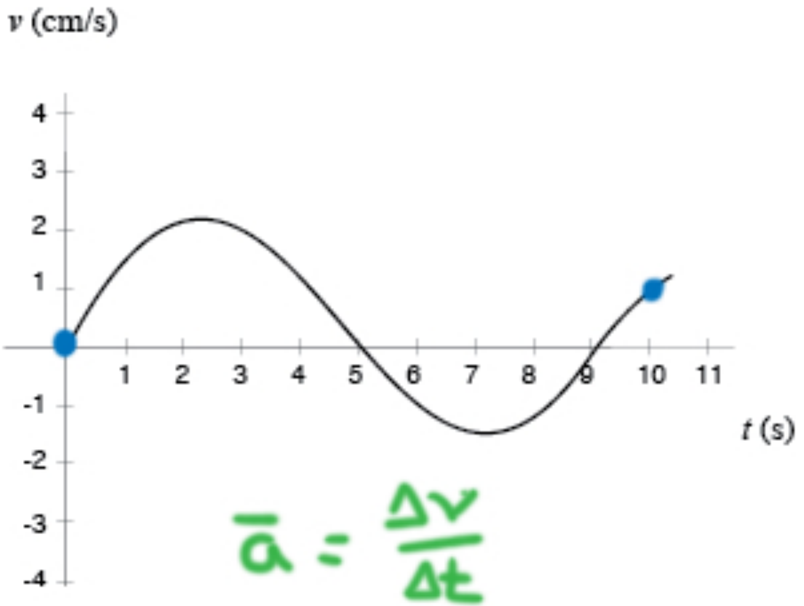
$$v^2 = v_0^2 + 2a(x - x_0)$$

constant acceleration

v	=	velocity
v_0	=	initial velocity
a	=	acceleration (constant)
$x\text{-}x_0$	=	change in position (displacement)

The accompanying graph was derived from measurements of blood velocity within the port of a hemodialysis catheter carried out over ten seconds. Which of the following is the nearest approximation of the average acceleration of a volume element within the blood during that time period?

A. $0.001\ m/s^2$
B. $0.01\ m/s^2$
C. $0.1\ m/s^2$
D. $10\ m/s^2$



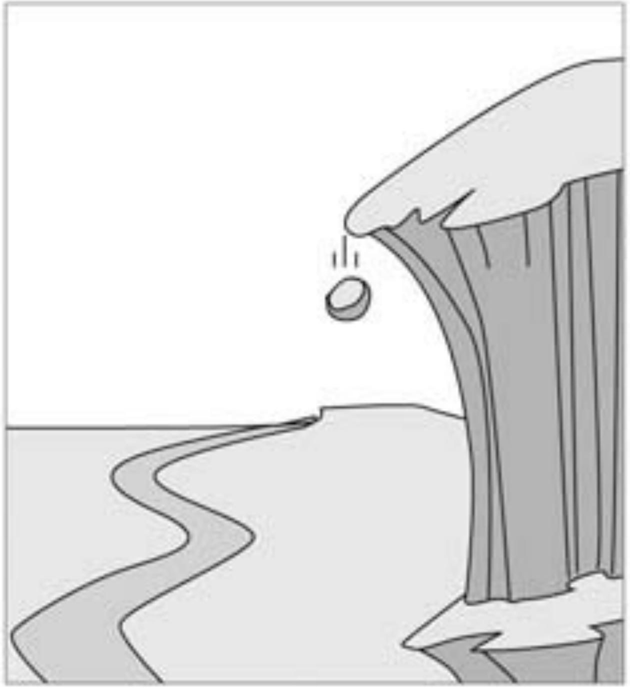
$$\bar{a} = \frac{\Delta v}{\Delta t}$$

$$\bar{a} = \frac{1\ cm/s}{10\ s} = 0.1\ cm/s^2$$

$$(0.1\ cm/s^2)\left(\frac{1\ m}{100\ cm}\right) = 0.001\ m/s^2$$

$$\bar{v} = \frac{\Delta x}{\Delta t}$$

Discounting air friction, approximately how far will the boulder have fallen in 3 seconds?



$$\Delta x = v_0 t + \frac{1}{2} a t^2$$

$$= \frac{1}{2}(10)(3)^2$$

$$= 45 m$$

a. 20 m

b. 45 m

c. 30 m

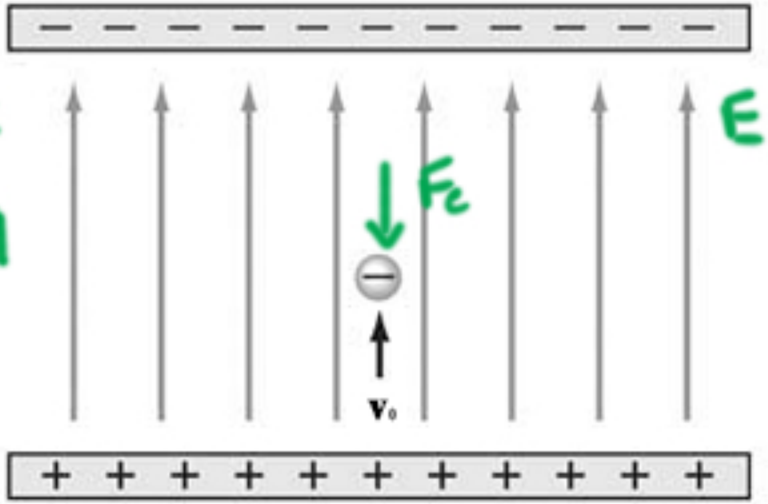
d. 90 m

Constant F

$F = Eq$

Constant a

$F = ma$



$t_{peak} = \frac{V_0}{a}$

If he throws it upwards at 30 m/s
How long to catch it again?

g

$g = -10\,m/s^2$

$\Delta v = at$

$t = \frac{\Delta v}{a}$

$t_{peak} = \frac{-30\,m/s}{-10\,m/s^2} = 3\,s$

$t_{total} = 2 t_{peak} = 6\,s$

The application of heat causes emission of an electron by the positive plate of a parallel plate capacitor. The electron moves into the uniform electric field between the plates with an initial velocity of 2.0×10^3 m/s perpendicular to the plate. The electron undergoes an acceleration of magnitude 4.0×10^7 m/s² perpendicular to the plates within the electric field. How long is the electron in flight?

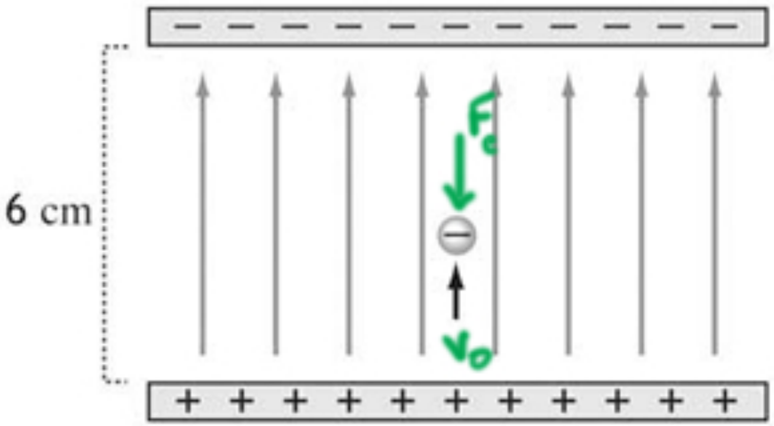
$$t_{peak} = \frac{2 \times 10^3 \text{ m/s}}{4 \times 10^7 \text{ m/s}^2} = 5 \times 10^{-5} \text{ s}$$

a. 2.0×10^{-5} s

b. 5.0×10^{-5} s

c. 1.0×10^{-4} s

d. 4.0×10^{-4} s



$$t_{tot} = 2\, t_{peak} = 1 \times 10^{-4} \text{ s}$$

Projectile Motion

$$v_x = v_{x_0} = \text{constant}$$

v_x = horizontal velocity
v_{x0} = initial horizontal velocity

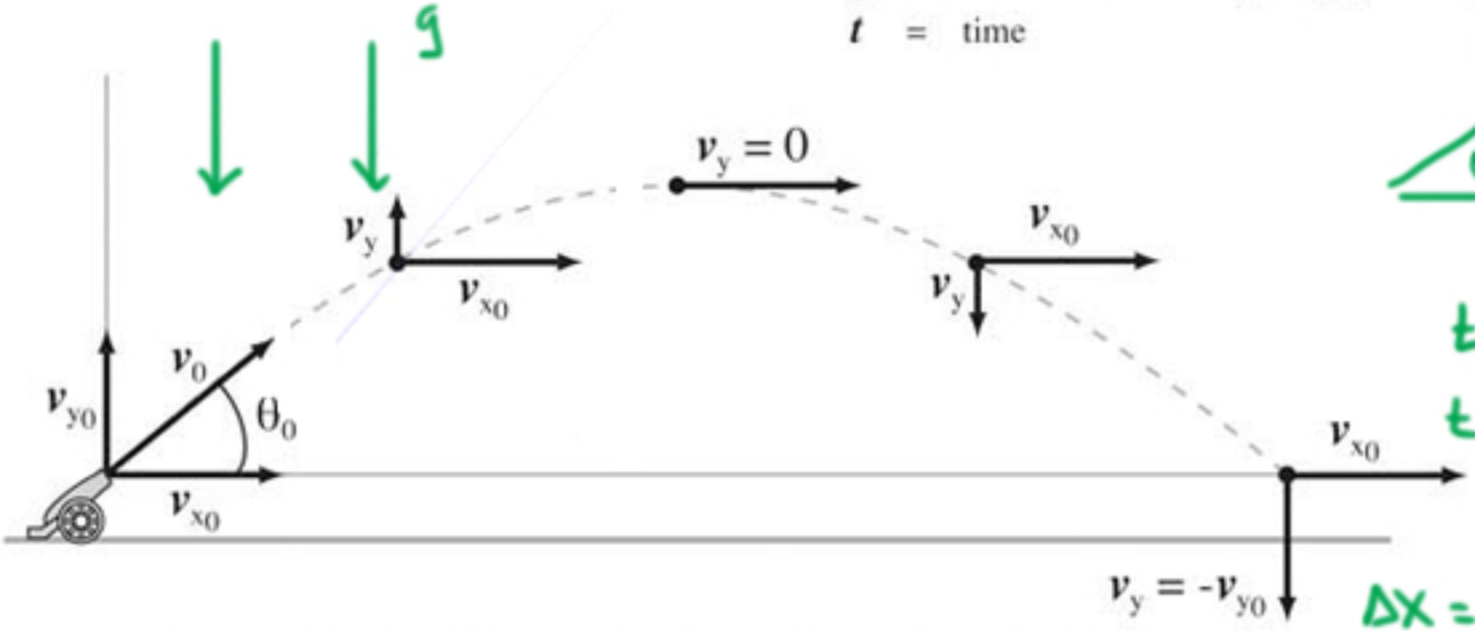
$$v_y = v_{y_0} - gt$$

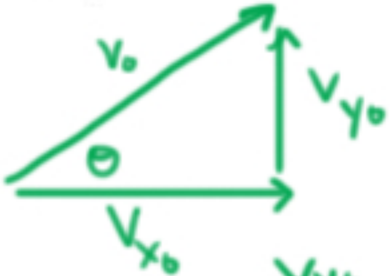
v_y = vertical velocity
v_{y0} = initial vertical velocity
g = acceleration due to gravity (9.8 m/s²)
t = time

$V_{y_0} = V_0 \sin\theta$

$V_{x_0} = V_0 \cos\theta$

$V_0 = V_{y_0} + V_{x_0}$





$t_{peak} = \frac{V_{y_0}}{g}$

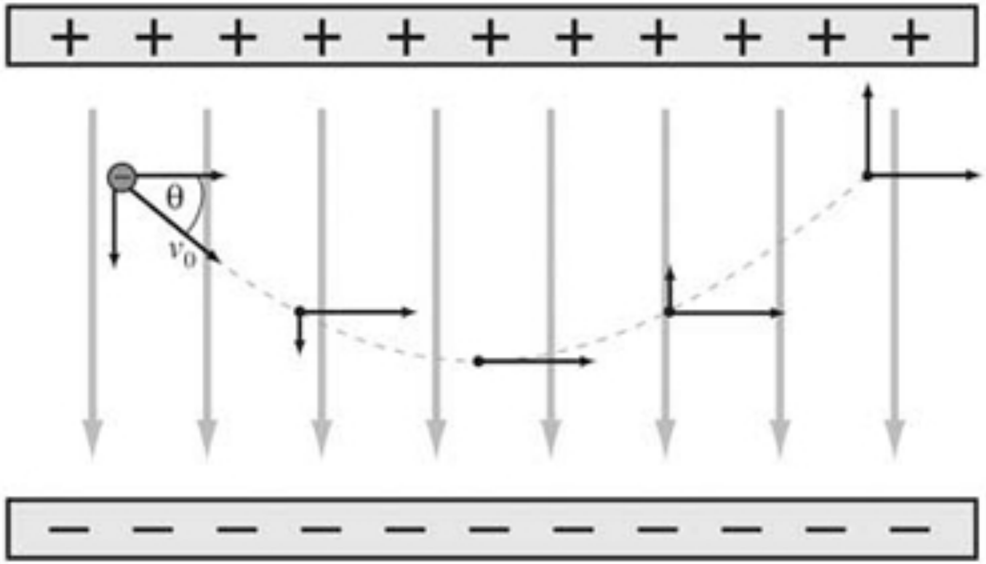
$t_{range} = \frac{2V_{y_0}}{g}$

$\Delta x = V_{x_0}\left(\frac{2V_{y_0}}{g}\right)$

range

The shape of the path of projectile motion is a parabola.

A charged particle experiences constant acceleration within a region occupied by a uniform electric field. A negatively charged particle moves into a uniform electric field with an initial velocity at an angle, θ, to the electric field. What kind of kinematics results?

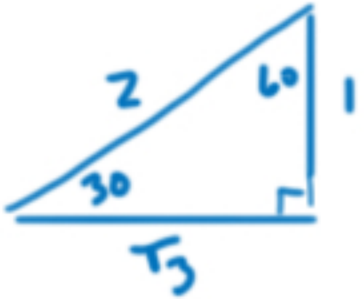


a. uniform circular motion

b. constant velocity

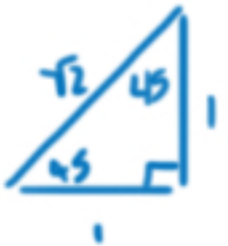
c. constant speed

d. parabolic motion

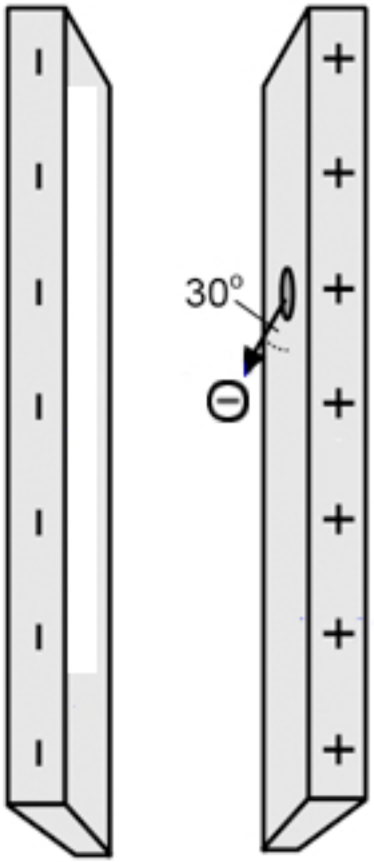


$\sin 30° = \cos 60° = \frac{1}{2}$

$\sin 60° = \cos 30° = \frac{\sqrt{3}}{2}$



$\sin 45° = \cos 45° = \frac{1}{\sqrt{2}} = \frac{\sqrt{2}}{2}$

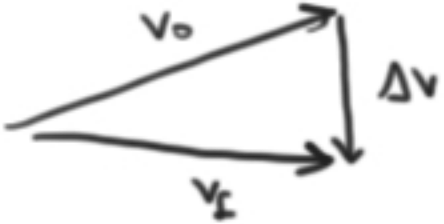


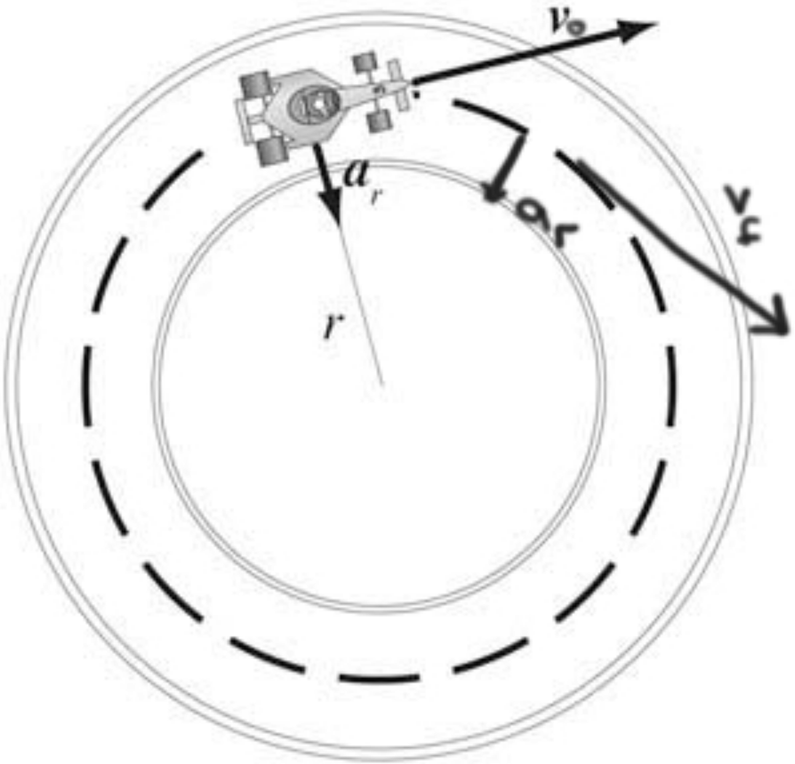
$v_\perp = v_0 \sin 30°$

$\sqrt{2} \sim 1.4 \qquad \sqrt{3} \sim 1.7$

Uniform Circular Motion

Constant speed on a circular path





$$a_r = \frac{v^2}{r} \qquad F_r = \frac{mv^2}{r}$$

a_r = centripetal acceleration
v = speed
r = radius

Does centripetal force perform work?

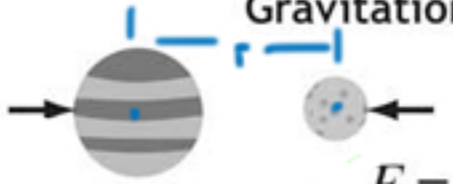
- Because F_r is always ⊥ to displacement, it performs no work

Dynamics and Newton's Laws

The Classical Fundamental Forces

Gravitation

Twice the distance → $\frac{1}{4}$ the F

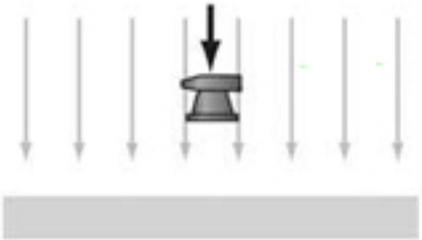


inverse square law forces

$$F = G\frac{m_1 m_2}{r^2}$$

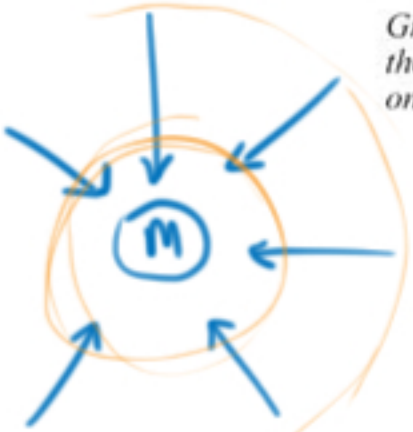
Gravitational force between two masses

$$F = \frac{G m_1 m_2}{(2r)^2} = \frac{1}{4}\frac{G m m_2}{r^2}$$



$$W = mg$$

Gravitational force on a mass within the uniform gravitational field on the earth's surface

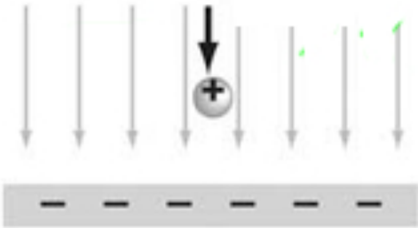


Electromagnetism

Electrostatic Force

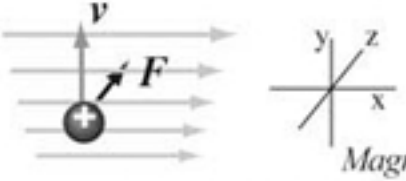
$$F = k\frac{q_1 q_2}{r^2}$$

Electrostatic force between two point charges



$$F = Eq$$

Electrostatic force on a point charge within a uniform electric field



$$F = qB\, v \sin\theta$$

Magnetic force on a point charge moving through a magnetic field

Magnetic Force

Newton's First Law

Law of inertia

An isolated object at rest will remain at rest. An object moving with uniform velocity will maintain that motion unless acted on by a net external force.

$\sum F = 0$ then $a = 0$

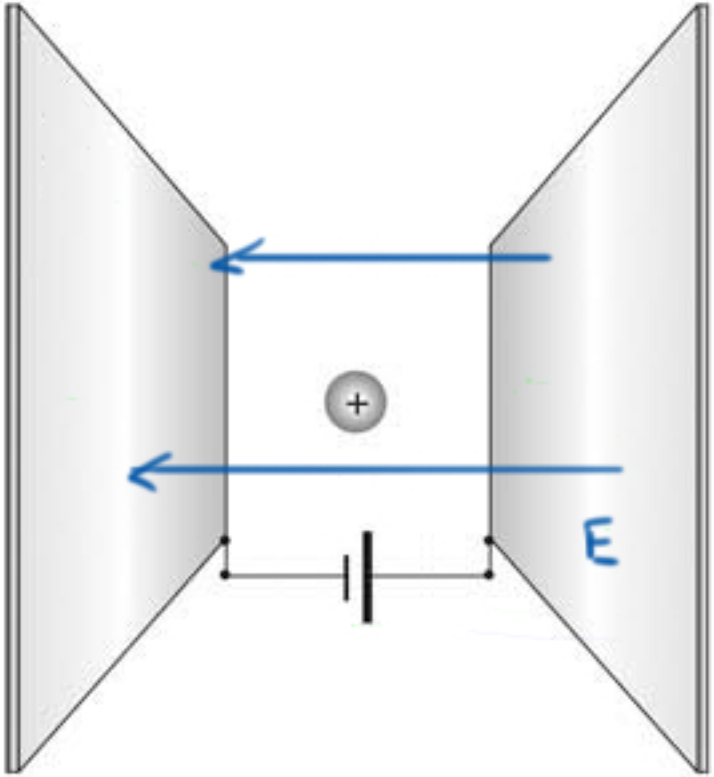
Newton's Second Law

$$F = ma$$ ★

Newton's Third Law

$$F_{12} = -F_{21}$$

A motionless, 20 kg, positively charged sphere is suspended in a weightless environment. An externally applied electric field subjects the sphere to a 10 N force for 4 seconds. At the end of four seconds, what is the speed of the sphere?



$F = ma$

$10\,N = (20\,kg)(a)$

$a = 0.5\,m/s^2$

$\Delta v = a\Delta t$

$= (0.5\,m/s^2)(2\,s)$

$= 2\,m/s$

a. 0.08 m/s

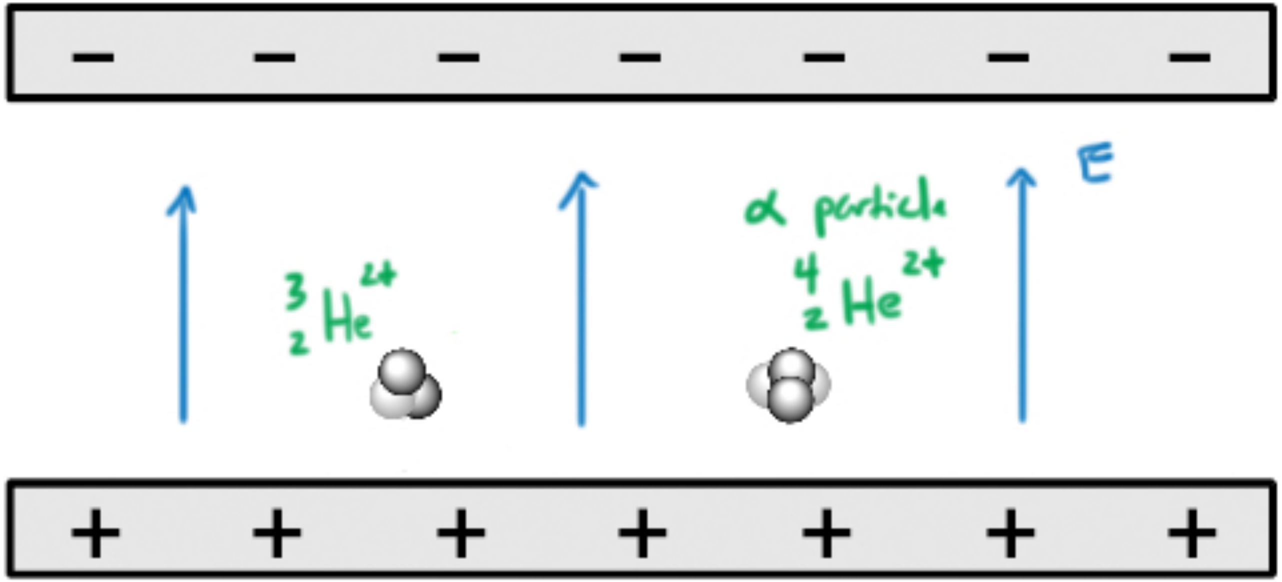
b. 0.5 m/s

c. 2.0 m/s

d. 8.0 m/s

${}^{4}_{2}He^{2+}$ and ${}^{3}_{2}He^{2+}$ are released from rest near the ⊕ plate

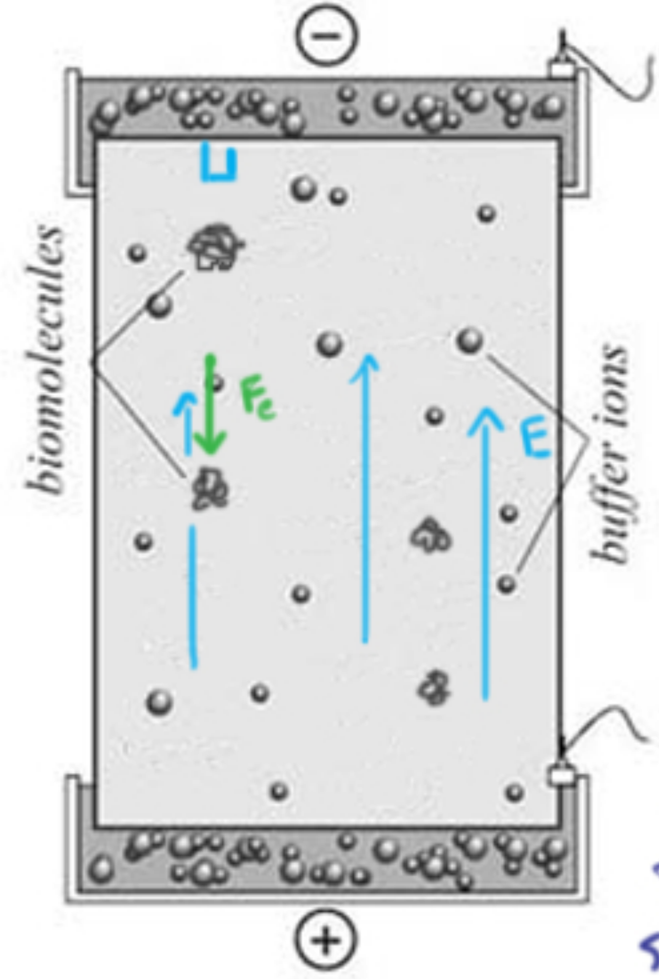
Which strikes the far plate 1st?



$F = Eq$ same force

$F = ma$ larger mass has lower a.

SDS-PAGE polyacrylamide gel electrophoresis



Sodium dodecyl sulfate (detergent)

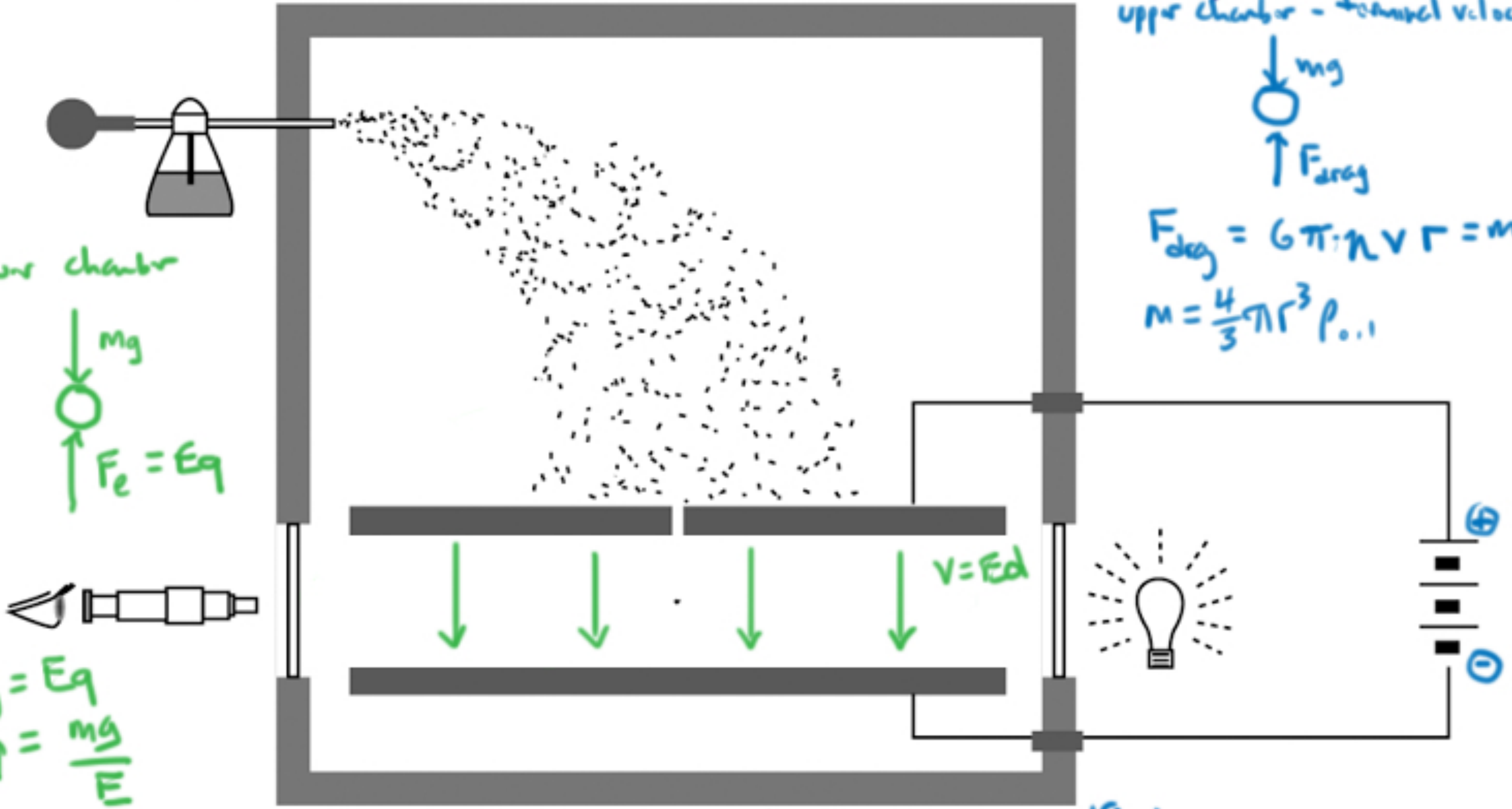
SDS coats proteins and gives them a uniform q/m ratio

protein reaches a constant mobility

This happens at a slower speed for bigger proteins.

terminal velocity

Millikan Oil Drop - Determined e - charge of an electron



upper chamber - terminal velocity

$\downarrow mg$, $\uparrow F_{drag}$

$F_{drag} = 6\pi\eta v r = mg$

$m = \frac{4}{3}\pi r^3 \rho_{oil}$

lower chamber

$\downarrow mg$, $\uparrow F_e = Eq$

$mg = Eq$

$q = \frac{mg}{E}$

q was always a simple multiple of $-1.6 \times 10^{-19}\,C = e$

1 J = N·m

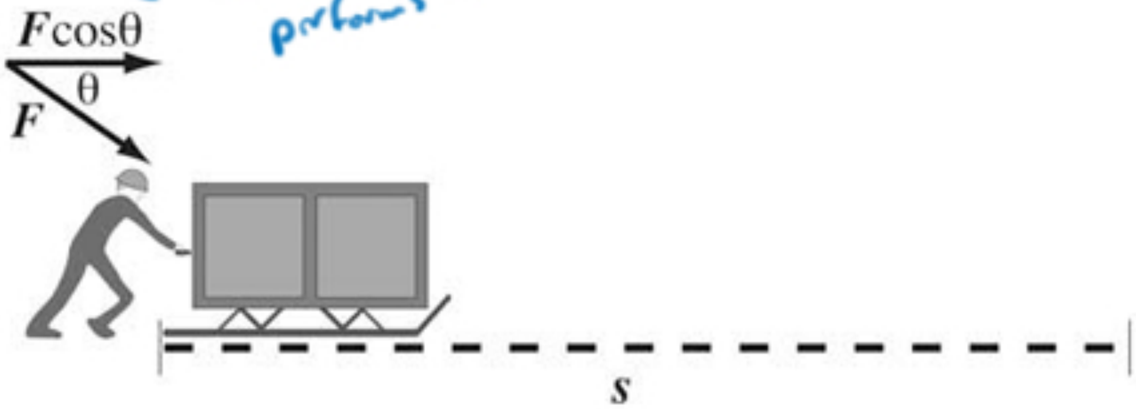
Mechanical Work

work = force · distance

$$W = (F \cos \theta)s$$

Work equals force parallel to the displacement times the displacement.

this component performs work



Kinetic Energy

$$K = \frac{1}{2}mv^2$$

K = kinetic energy
m = mass
s = speed

Work = ΔKE

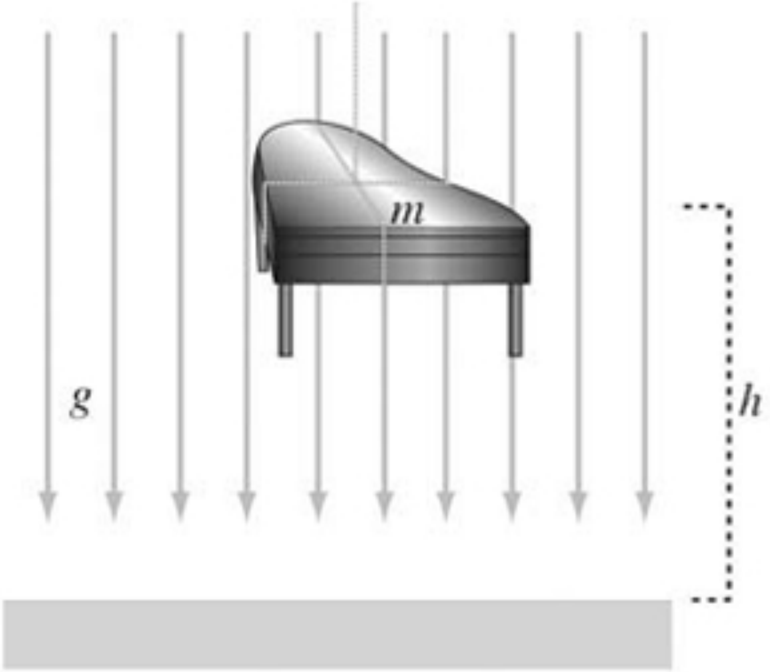
KE is the work invested in the motion or the work required to bring to rest.

A jet with quadruple the mass moving at half the speed of the smaller jet possesses an equal amount of kinetic energy.

Potential Energy

$$U = mgh$$

U = potential energy
m = mass
g = acceleration due to gravity ($9.8\ m/s^2$)
h = height



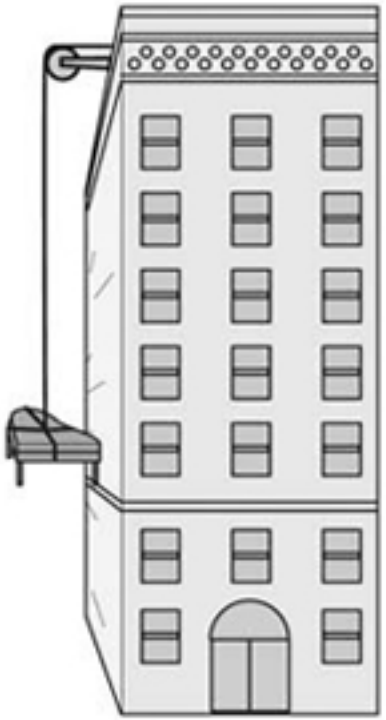
What is the minimum work required to raise a 500 kg piano from street level to a window at 20m elevation?

a. 10,000 J

b. 25000 J

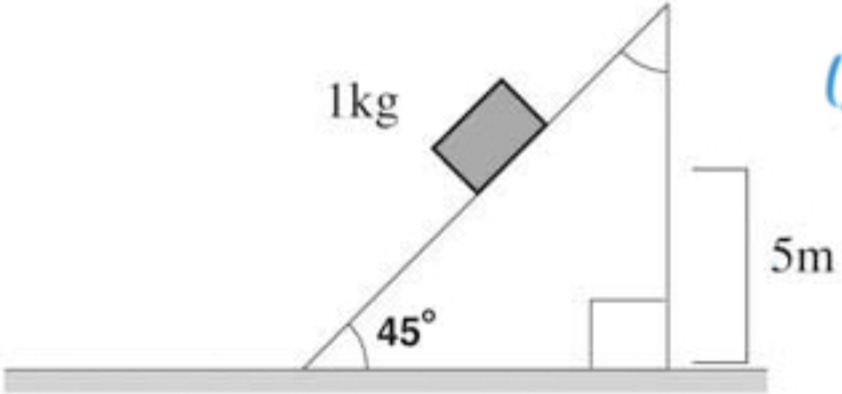
c. 100,000 J

d. 2.0×10^5 J



A 1kg block is released from a vertical height of 5m to begin sliding down a frictionless 45° inclined plane. What is the speed of the block when it reaches the base of the plane?

Don't do this



$PE_i = KE_f$

$(1kg)(10\,m/s^2)(5m) = \frac{1}{2}(1kg)v^2$

$v^2 = 100\,m^2/s^2$

$v = 10\,m/s$

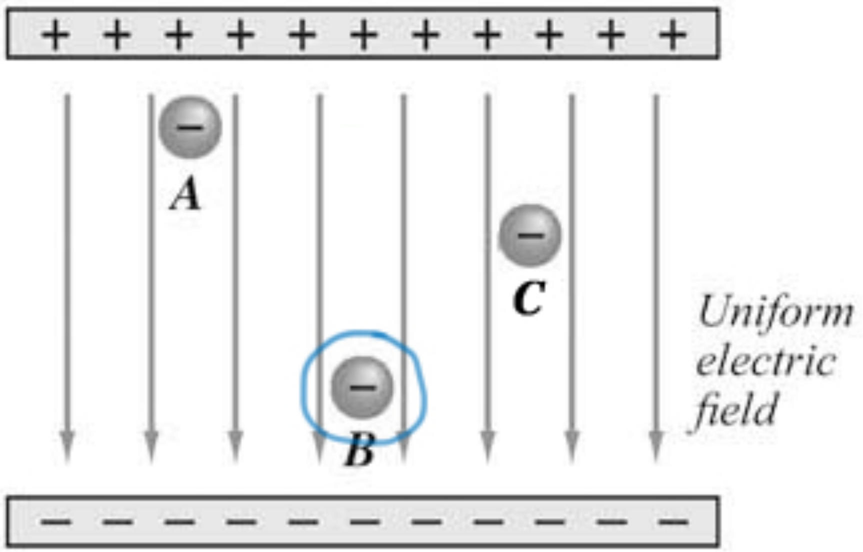
a. 1.7 m/s

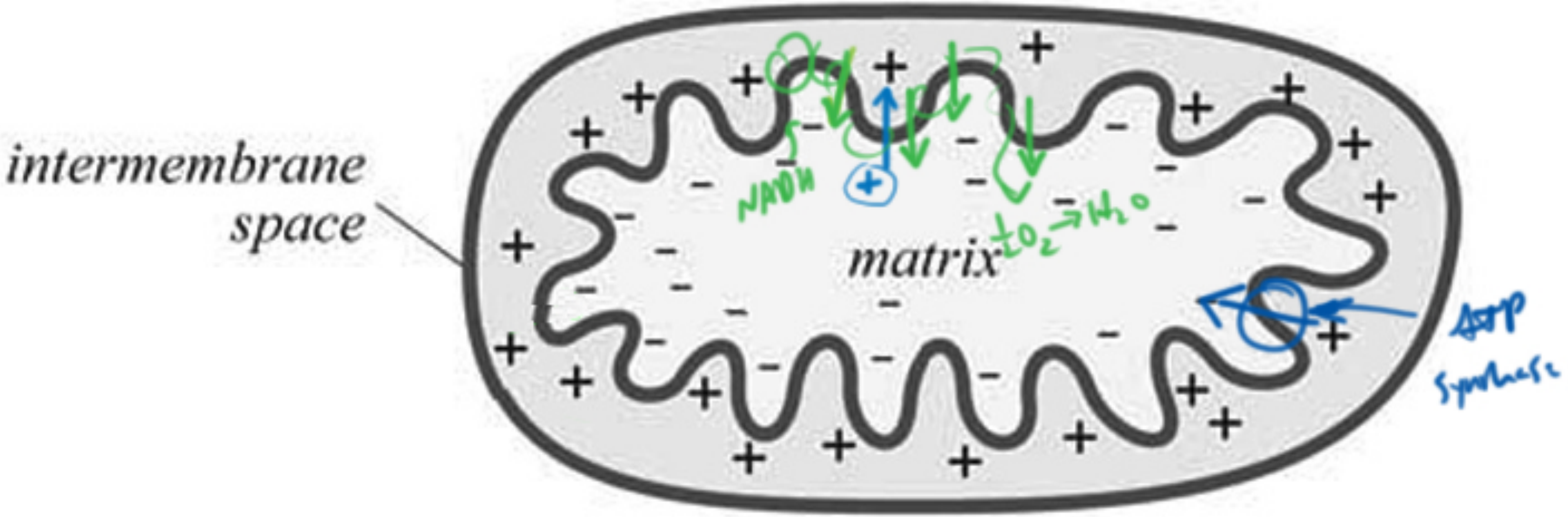
b. (5) ($\sqrt{2}$) m/s

c. 10 m/s

d. 45 m/s

Shown below are the locations of three electrons within the electric field between the plates of a parallel plate capacitor. If electric force from the plates is the only significant force on the particles, which electron has greater potential energy?



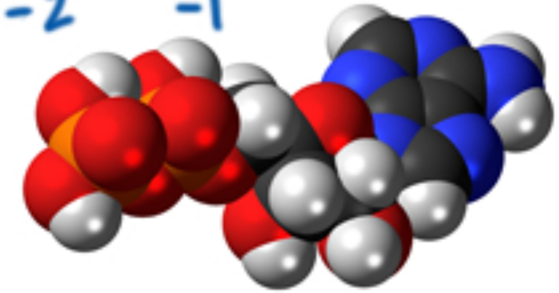

intermembrane space
matrix
NADH
$\frac{1}{2}O_2 \rightarrow H_2O$
ATP Synthase

P_i

-2

ADP

-2 -1

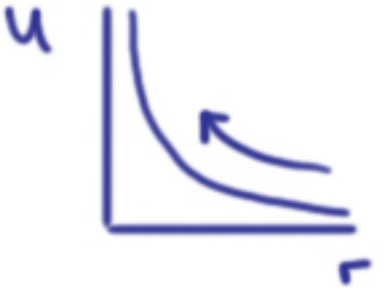


$$ADP + P_i \longrightarrow ATP$$

$$U_e = \frac{k q_1 q_2}{r}$$

$\longrightarrow$ (-2)

(-3) $\longleftarrow$

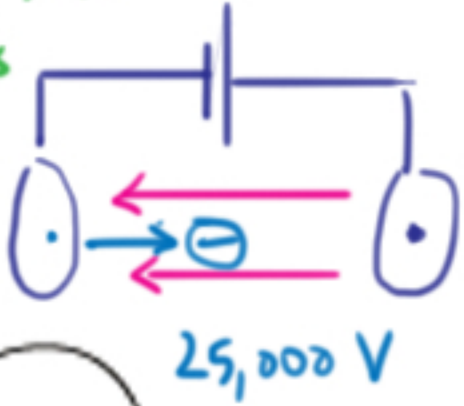


What is the kinetic energy of an electron entering the cathode ray tube shown below?

$e = 1.6 \times 10^{-19}\ C$

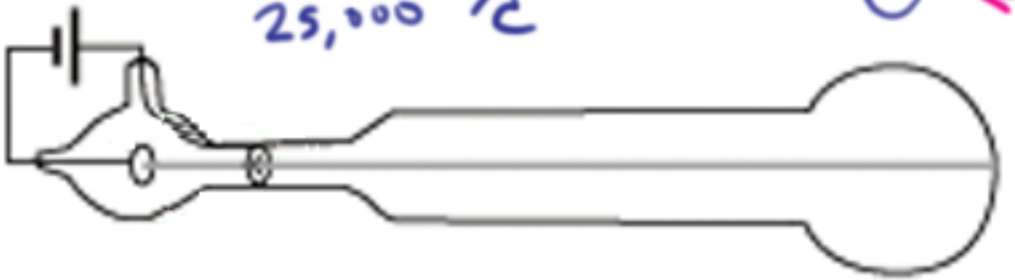
$(2.5 \times 10^{4}\ J/C)(1.6 \times 10^{-19}\ C) = 4 \times 10^{-15}\ J$

We could also have said instead of 4×10^{-15} J
25,000 eV ← 1 eV - the work 1 V does on a single ⓔ



$1\ V = J/C$

25,000 V ← means 25,000 J/C



$1\ eV = 1.6 \times 10^{-19}\ J$

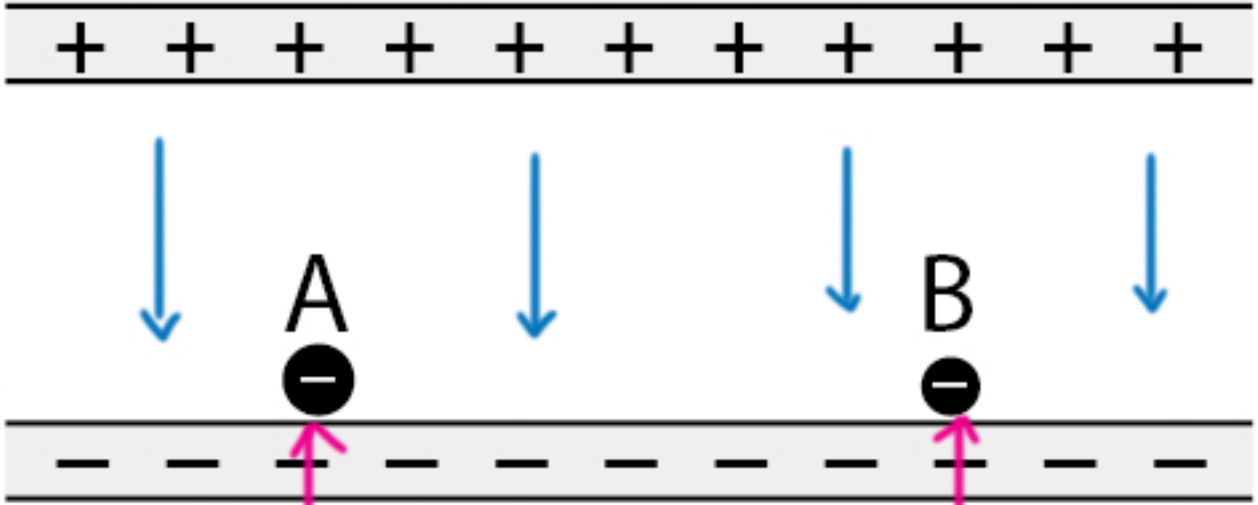
$q_A = q_B$ $m_A = 4m_B$

$KE = \frac{1}{2}mv^2$

$\frac{1}{2}m_A v_A^2 = \frac{1}{2}m_B v_B^2$

$\frac{v_A}{v_B} = \frac{\sqrt{m_B}}{\sqrt{m_A}}$

Four times the mass means half the speed.



F_e

$F = Eq$

same force

same work

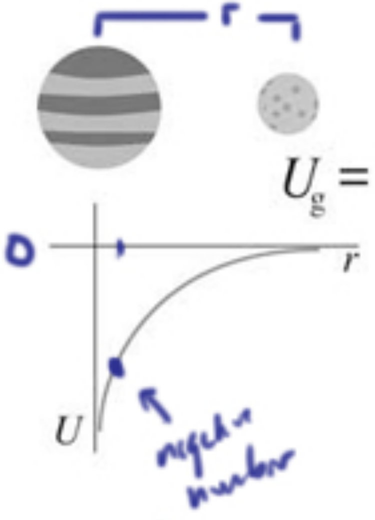
$\Delta KE = work$

Which strikes with greater kinetic energy? or is it the same?

Gravitational and Electrostatic Potential Energy

system of two masses or two point charges

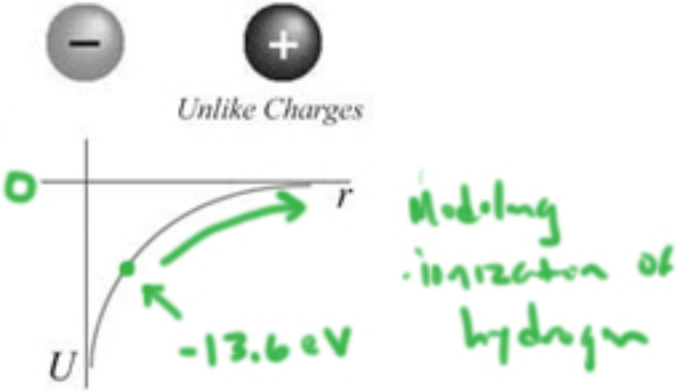
$$U_g = -G\frac{m_1 m_2}{r}$$

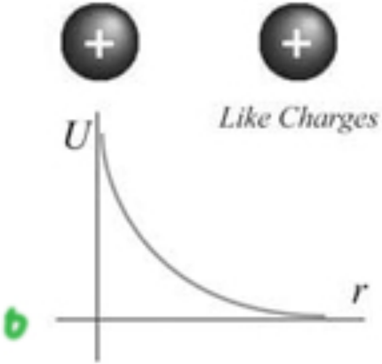


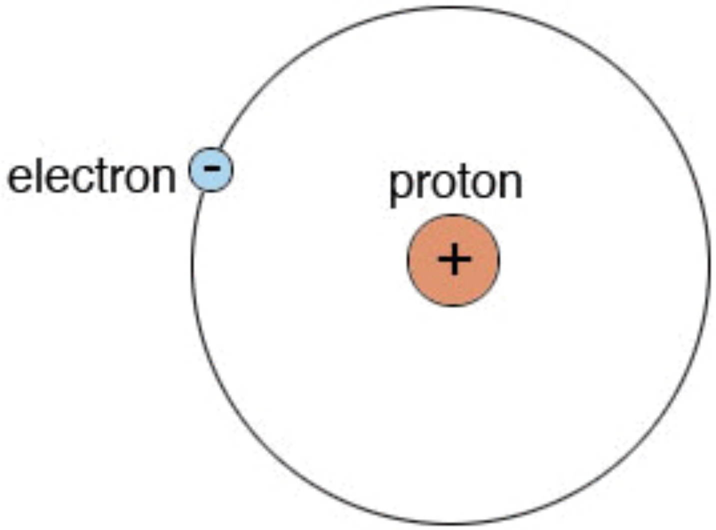
$$\lim_{r \to \infty} U_g = 0$$

the well of gravitational binding energy.

$$U_e = k\frac{q_1 q_2}{r}$$







While classical physics
is a crucial heuristic
for chemistry, remember
that the atom is
a quantum
electrodynamic system

Which of the following occurs with an increase in electrostatic potential energy?

A. A gaseous sodium ion captures an electron.

B. Negative charges introduced at a point on a neutral metal sphere spreads over its surface area with uniform distribution.

C. One glucose molecule reacts with six molecules of oxygen to form six molecules of carbon dioxide and six molecules of water.

$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$

$\Delta U = Q - W$ ← not now

D. A globular polypeptide unfolds from its native configuration in high temperature conditions.

Fluid Mechanics

Density

SI units - $\frac{kg}{m^3}$

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

ρ = density
m = mass
V = volume

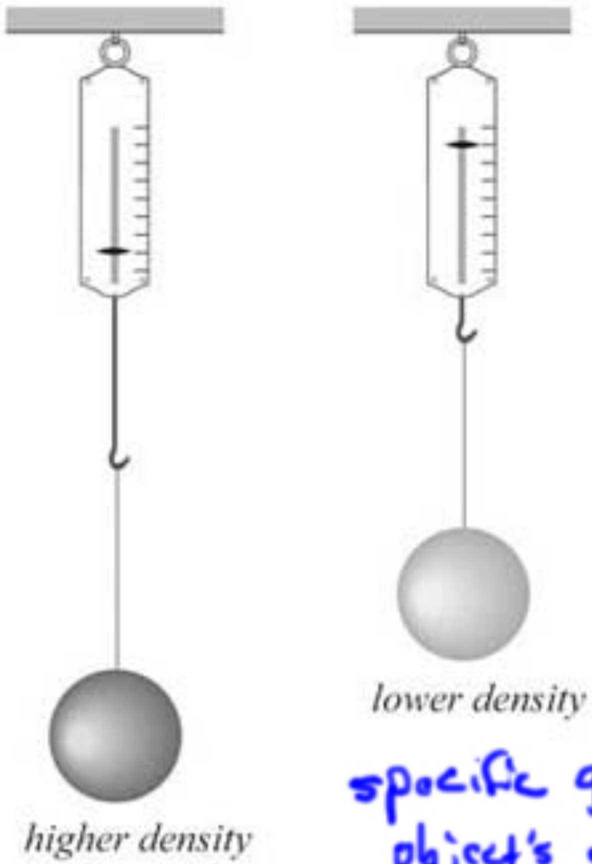
Density is the mass per unit volume

ρ_{H_2O} - $\frac{1000 kg}{m^3}$

- $\frac{1g}{cm^3} = \frac{1g}{cc}$

- $\frac{1g}{mL}$

- $\frac{1kg}{L}$

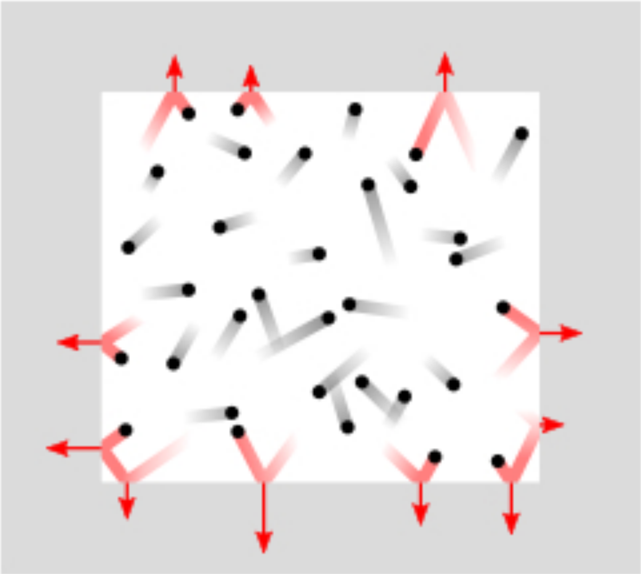


specific gravity - ratio of an object's density to the density of water.

Pressure

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

P = pressure
F = force
A = area



$1\ N/m^2 = 1$ Pascal

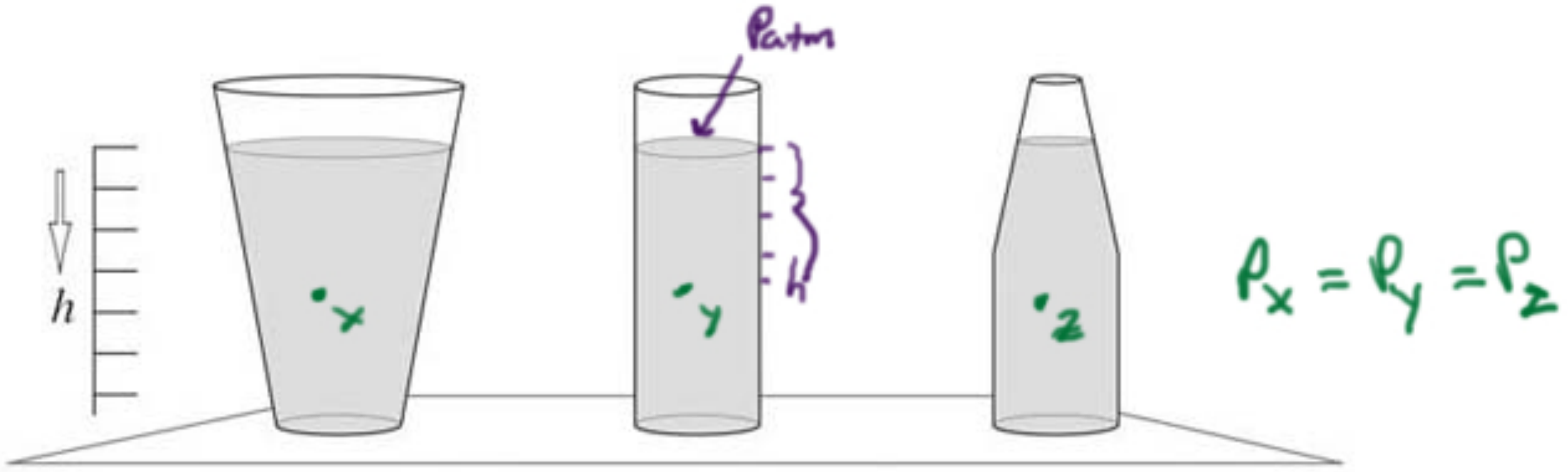
1 atm = 101,000 Pa
1×10^5 Pa ← exactly 1 bar
= 760 mm Hg
= 760 torr

Pressure Increases with Depth

$$P = P_a + \rho g h$$

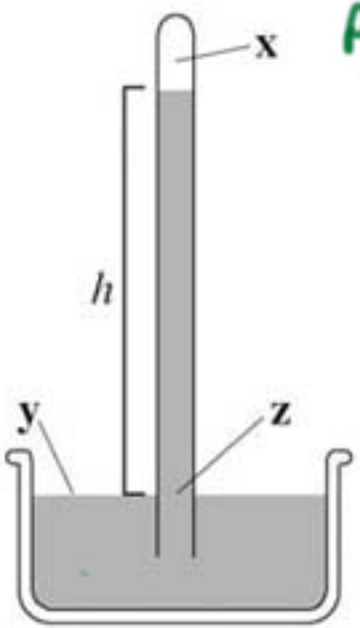
density

P = pressure
P_a = atmospheric pressure
ρ = density
g = acceleration due to gravity ($10 m/s^2$)
h = depth



Pressure is independent of the shape and size of the container.

With the common mercury barometer pictured at right, the atmospheric pressure is equal to the product of $\rho g h$ (ρ is the density of mercury). Which of the following is *not* always true with regard to this device when it is accurately measuring atmospheric pressure?



a. P_x is very nearly a vacuum

b. $P_y = P_z$

c. $P_y = P_{atm}$

d. $P_y = 760$ torr

$P_x \sim$ vacuum

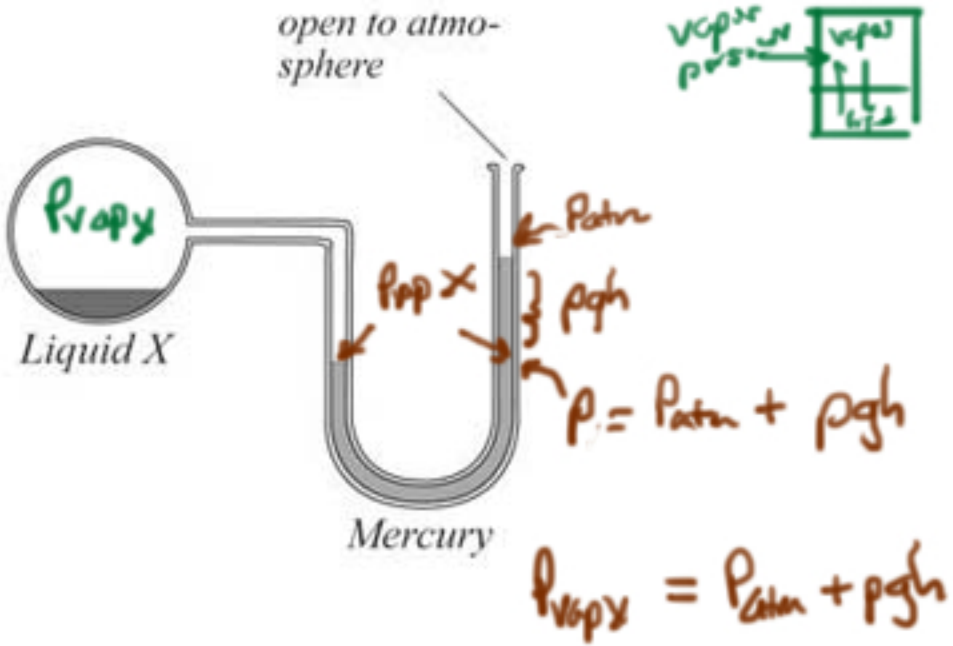
$P_z = P_y$

$P_y = P_{atm}$

$P_z = \rho_{Hg} g h$

$P_{atm} = \rho g h$

After adding a 50 ml sample of *Liquid X* to the vacuum bulb at right, it was observed to boil within the bulb. After a time, the system reached the state shown at right, the boiling having ceased. Assume that the vapor pressure of mercury at this temperature is nearly zero (pressure of the gaseous phase above its liquid phase) what can we conclude from the experiment?



a. The density of *Liquid X* is greater than the density of mercury.

b. *Liquid X* possesses implausible properties.

c. The vapor pressure of *Liquid X* at room temperature is higher than atmospheric pressure.

d. The bouyancy of *Liquid X* is greater than the bouyancy of mercury.

Pascal's Law

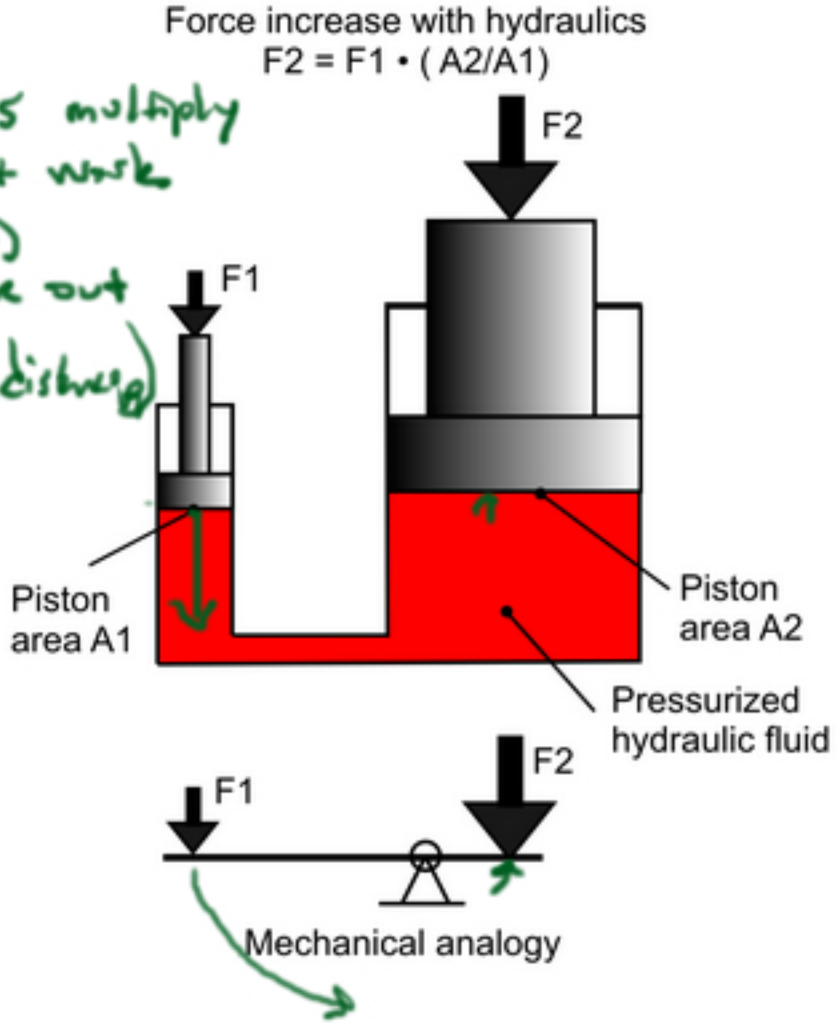
$$\frac{F_a}{A_a} = \frac{F_b}{A_b}$$

F = force
A = area

simple machines multiply force but not work (at best)

work in = work out

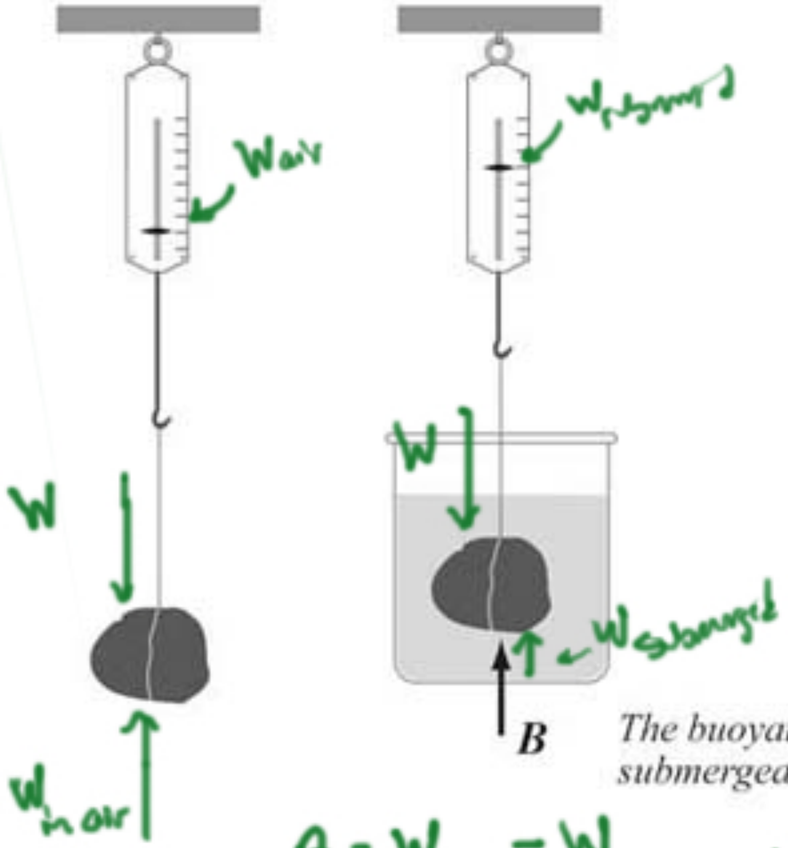
$(\text{force}_A)(\text{distance}_A) = (\text{force}_B)(\text{distance}_B)$



Pascal's Law states that an increase in the pressure on one of the surfaces enclosing a fluid will be transmitted as an undiminished increase in pressure to all parts of the fluid. This means for our hydraulic press at right that one hundred newtons exerting over one square meter, can hold up four hundred newtons over four square meters.

Archimedes' Principle

$$\text{specific gravity} = \frac{W_{air}}{W_{air} - W_{submerged}}$$



The buoyant force acting on a submerged mass

$$B = W_{air} - W_{submerged}$$

$W = W_{air}$

$$B = W_{\text{fluid displaced}}$$

B = Buoyant Force

$W_{\text{fluid displaced}}$ = weight of fluid displaced

- Submerged object -
  volume of object → volume of water → mass of water → weight = B
- floating object
  start with force equilibrium

% submerged = specific gravity

A bar of lead has the dimensions $2 \times 3 \times 5$ cm³ and mass 330 g. What is the specific gravity of lead?

A. 1
B. 10
C. 11
D. cannot be determined from given information

ρ?

$\frac{330\text{ g}}{30\text{ cm}^3} = 11\text{ g/cm}^3$

If the bar of lead were submerged in water, what would be the apparent loss of weight on the bar?

A. 300 N
B. 1 N
C. 0.3 N
D. 1/11 N

apparent loss of weight means buoyant force.

displaces 30 cm³ H_2O

= 30 g H_2O = .03 kg

$W = mg = 0.3$ N

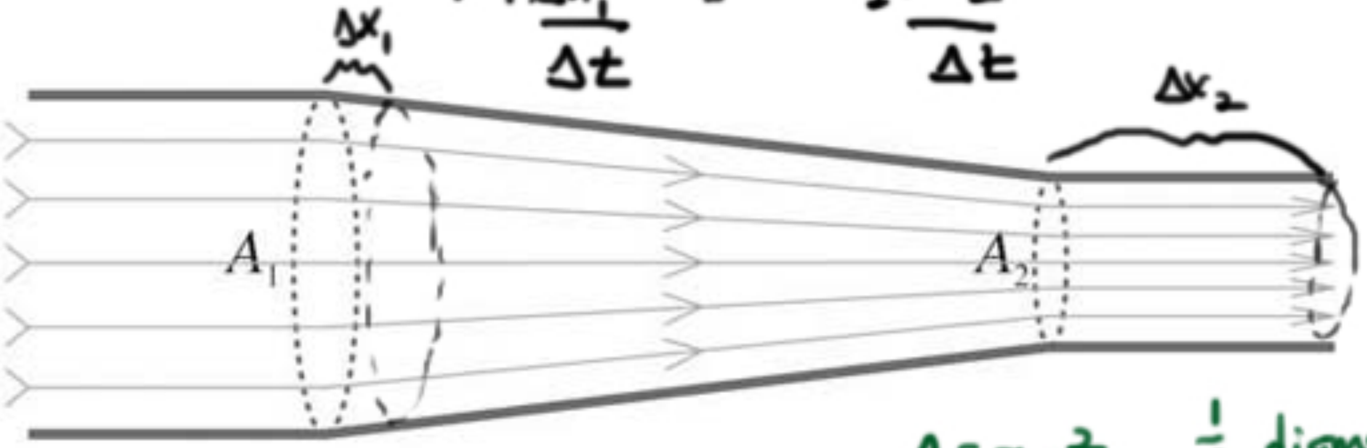
Continuity of Volume Flux

flow speed

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

A = vessel cross-sectional area
v = flow speed

$$A_1 \frac{\Delta x_1}{\Delta t} = A_2 \frac{\Delta x_2}{\Delta t}$$



Ideal Fluid
- incompressible
- only laminar flow
- no viscosity

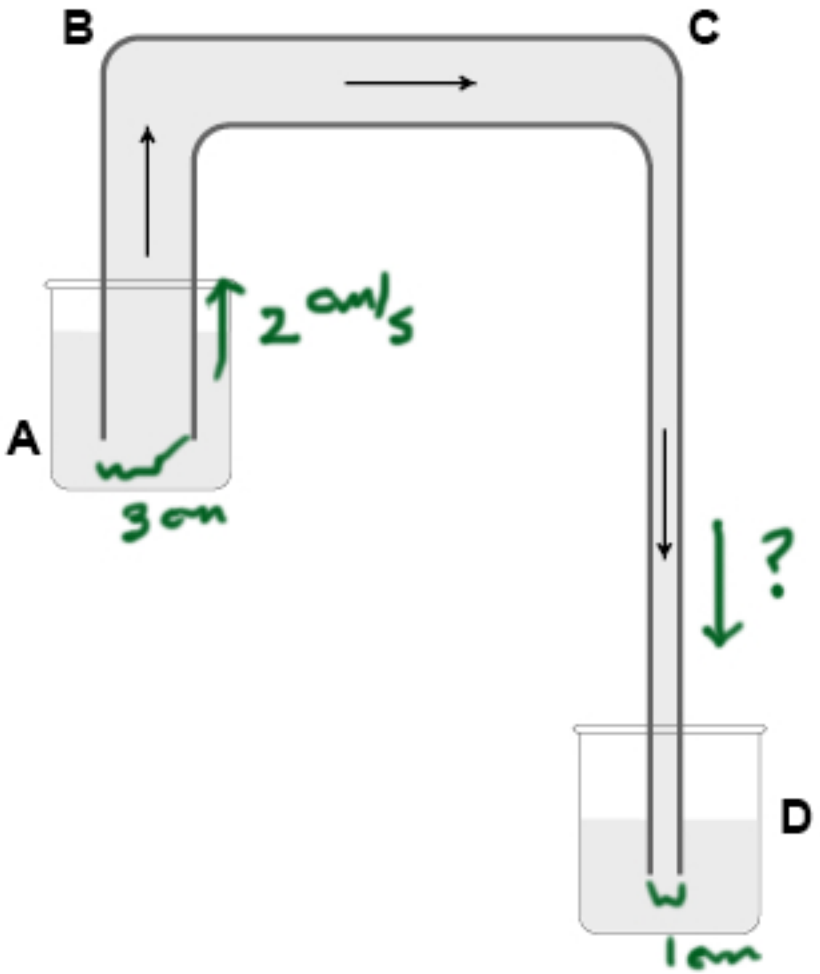
Volume Flux = $\frac{\text{volume}}{\text{time}}$

$\frac{gal}{s}$ $\quad$ m^3/s

Volume Flux = $Q = Av$

$A = \pi r^2$ $\quad$ $\frac{1}{2}$ diameter = 4 times flow speed

In the flow of an ideal fluid, the rate at which fluid volume moves through the vessel (volume flux) is the same everywhere along the pipe. Where vessel diameter is narrowest, the flow speed is greatest.



The diameter of tube segment AB is 3 cm. The diameter of tube segment CD is 1 cm. When the flow speed through AB is 2 cm/s, what will the flow speed be through CD?

A. 6 cm/s
B. 18 cm/s
C. 9 cm/s
D. 15 cm/s

$A_1 v_1 = A_2 v_2$

$A = \pi r^2$

$\left(\frac{1}{3} r\right)^2 = \frac{1}{9} r^2$

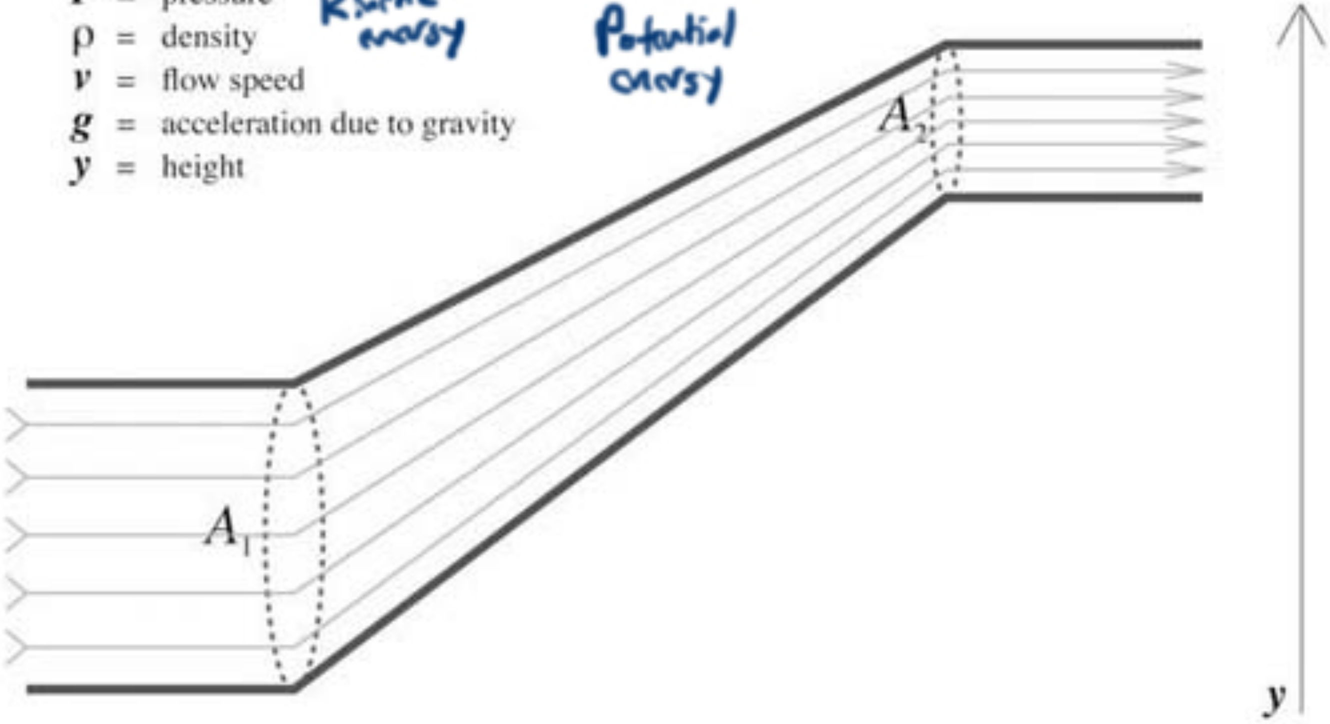
$\frac{1}{3}$ radius $\Rightarrow$ $\frac{1}{9}$ area conservation of energy / volume constant

Bernoulli's Equation

$$P + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$$

pressure ↑ (P) Kinetic energy ↑ ($\frac{1}{2}\rho v^2$) Potential energy ↑ ($\rho g y$)

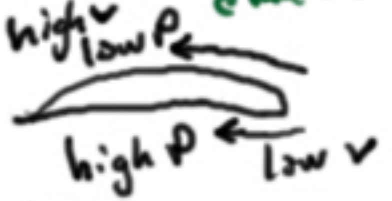
P = pressure
ρ = density
v = flow speed
g = acceleration due to gravity
y = height



By far the most common problem - level flow where interchange between P and $\frac{1}{2}\rho v^2$

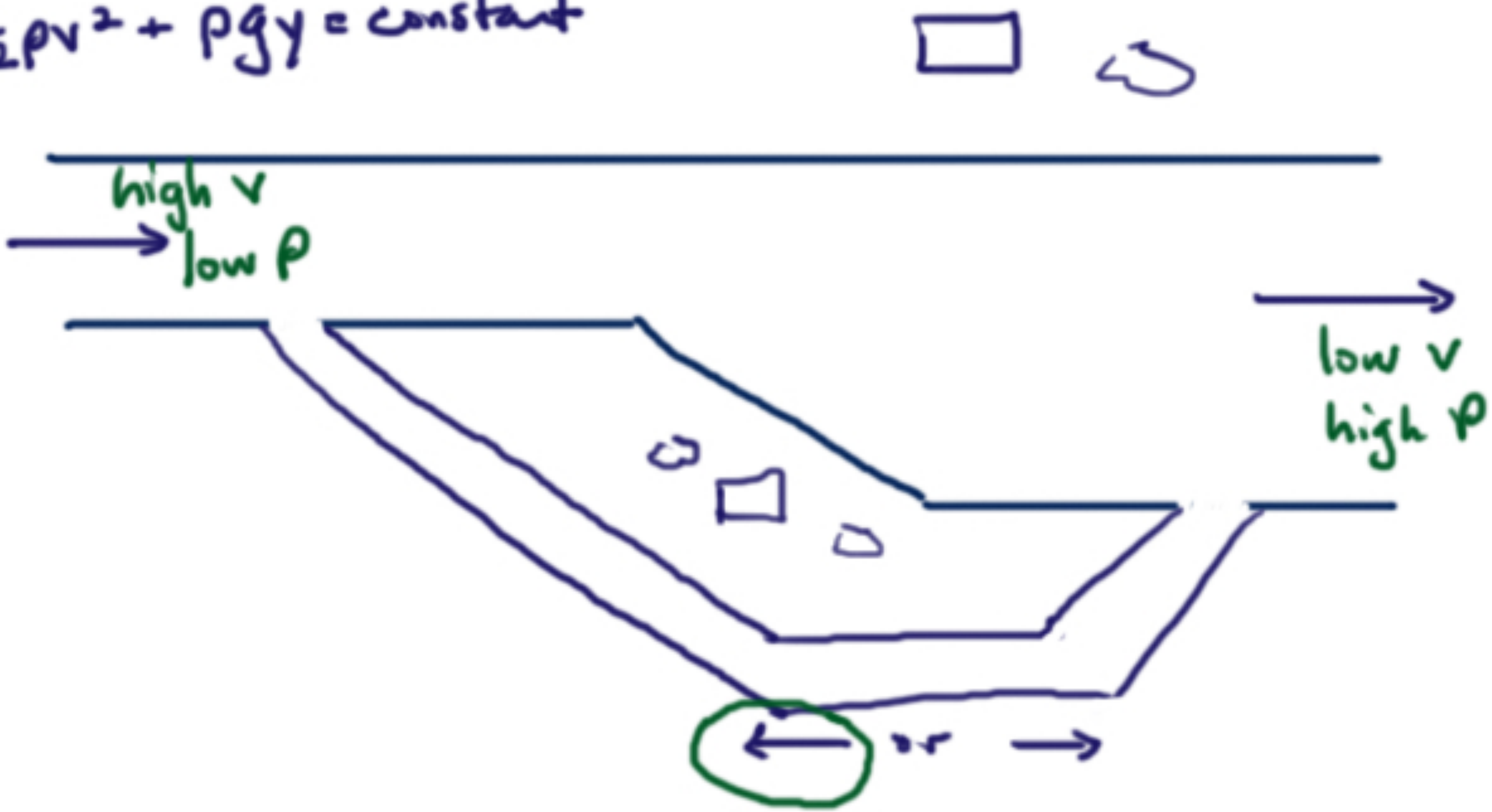
Where flow speed is high, pressure is low

↑ venturi effect



$$A_1 v_1 = A_2 v_2$$

$$p + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$$



canals - uniform depth

bird's eye view

An aneurysm is caused by the weakening of the arterial wall where a bulge occurs and the cross-section of a vessel increases considerably. At the cross-section of an aneurysm

A. flow velocity will be reduced and the pressure will be reduced

B. flow velocity will be reduced and the pressure will increase

C. flow velocity will increase and the pressure will be reduced

D. flow velocity will increase and the pressure will increase

Real Fluids

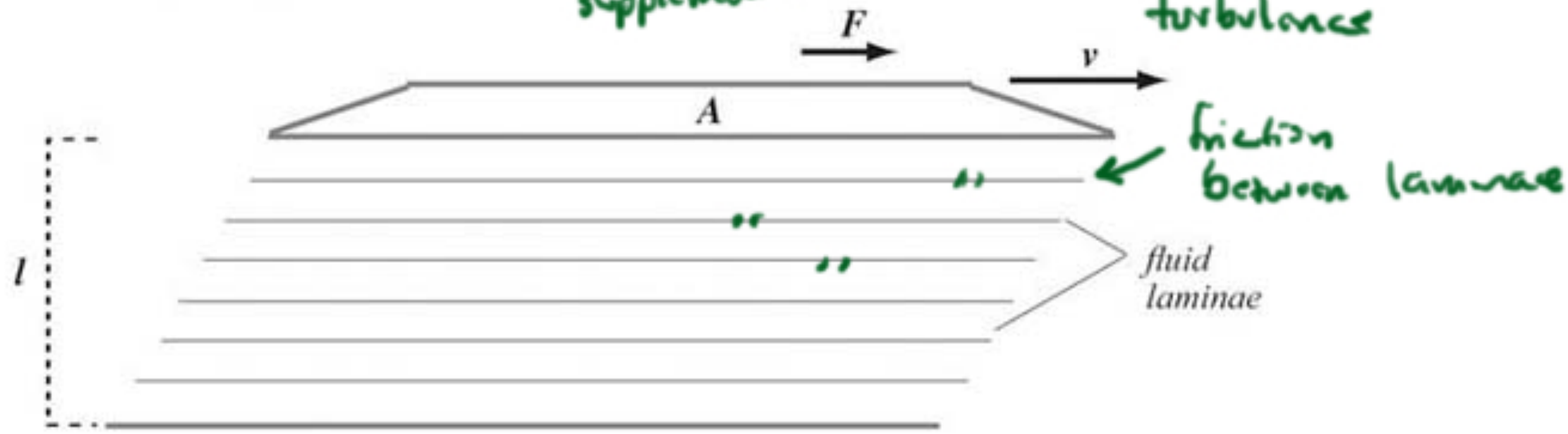
Viscosity

- Viscosity leads to resistance to flow (Poisseuille's Law)
- Viscosity opposes turbulence

η = viscosity
F = shearing force
A = sheared area
v = sliding speed
l = fluid thickness

$$\eta = \frac{F/A}{v/l}$$

↑ supplemental



The figure above shows laminae, or layers of liquid, between two surfaces. The more viscous the fluid, the larger the shearing force required for the top surface to slide past the bottom surface at a given speed. Viscosity reflects friction between the laminae, or fluid layers.

The Causes of Turbulent Flow

$$RN = \frac{\rho v d}{\eta}$$

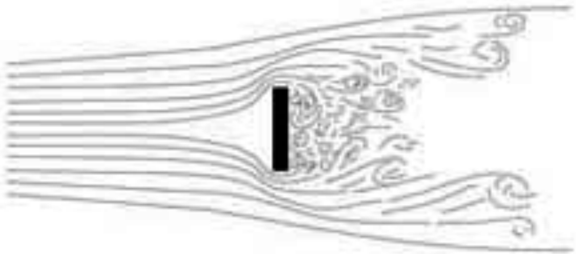
density → ρ; speed → v; geometric property → d; viscosity → η

RN > 3000 turbulence is likely

RN	=	Reynolds number
ρ	=	fluid densitiy
v	=	flow speed
d	=	geometrical property of the flow (diameter of obstruction, pipe width)
η	=	viscosity

laminar (streamline) flow

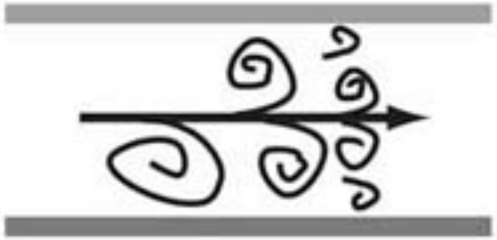
(low Reynolds number)



turbulent flow

(high Reynolds number)

Most blood flow is remarkably free of turbulence, although, under both normal or abnormal conditions, turbulence may occur in certain areas of the circulatory system. Which of the following would be most likely to directly contribute to turbulence?



$$RN = \frac{\rho v d}{\eta}$$

$$A_1 v_1 = A_2 v_2 = Q$$

a. decreased cardiac output

b. increased blood viscosity

c. localized narrowing of an arterial vessel

d. decrease in blood density

Poiseuille's Law

!

2 ways to look at this

$$Q = \frac{\Delta P \pi r^4}{8 \eta l}$$

Q	=	volume flux
ΔP	=	change in pressure
r	=	pipe or vessel radius
η	=	viscosity
l	=	pipe or vessel length

ΔP as effect ↓

1) What leads to high Q (volume flux)

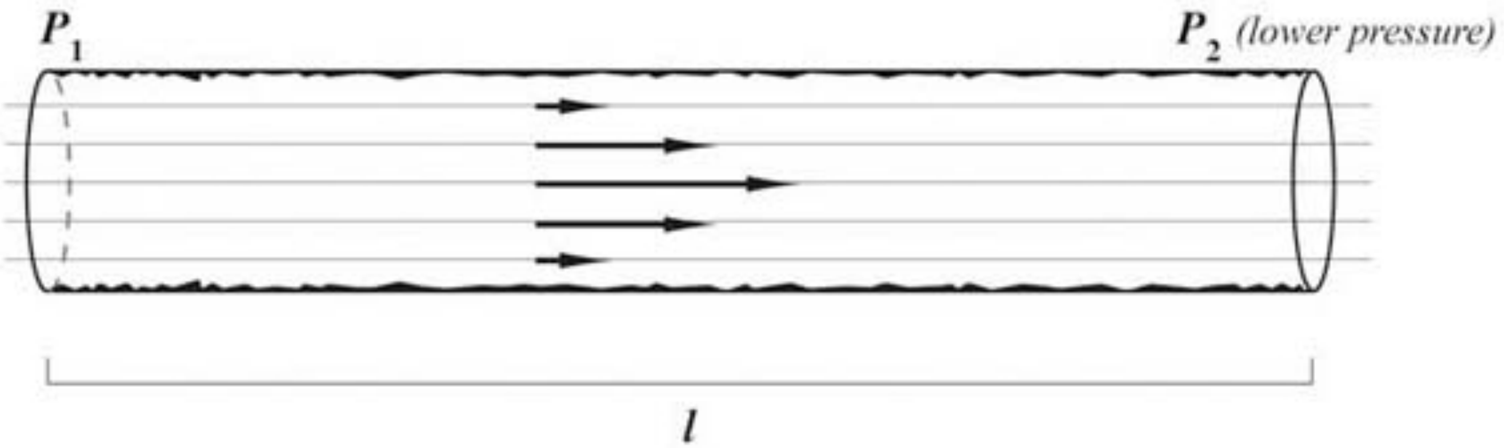
$\frac{\Delta P}{l}$ big pressure gradient r^4 large vessel η low viscosity

↑ ΔP as cause

2) What leads to a big ΔP?

Viscous dissipation

small r, big η



$$Q = \frac{\Delta P \pi r^4}{8 \eta l}$$

With the plunger exerting the same negative pressure, the total time required to draw 10ml of blood through a syringe with a needle having half the length and half the diameter would be

A. 1/2 as long
B. the same
C. 8 times longer
D. 32 times longer

$$\frac{1}{2} l \Rightarrow 2 \times Q$$

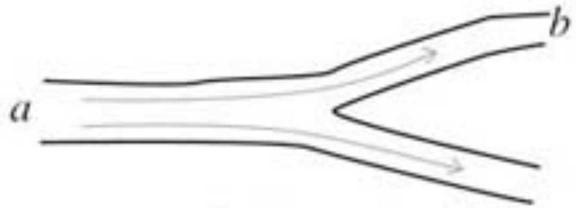
$$\frac{1}{2} r \Rightarrow \frac{1}{16} \times Q$$

$$\frac{1}{8} Q$$

A large artery branches into two smaller arteries, each with 50% of the radius of the larger. Since all blood flowing into the junction enters the smaller arteries, the volume flux within the larger must be twice the volume flux through either of the smaller. Thus, from Poiseuille's Law:

$$\frac{\Delta P_a r_a^4}{l_a} = \frac{2 \Delta P_b r_b^4}{l_b}$$

Which follows from this relationship?



$$Q = \frac{\Delta P \pi r^4}{8 \eta l}$$

Poiseuille's Law

Q = volume flux
ΔP = change in pressure
r = vessel radius
η = viscosity
l = vessel length

a. Pressure drop per unit length is much greater in a small artery than in the large.

b. Pressure drop per unit length is double in the large artery vs. the small.

c. Total flow speed in the small arteries equals total flow speed in the large.

d. Pressure drop per unit length is double in the small artery vs. the large.

The answer is (a)

Because of the extreme effect of the decreasing radius on viscous dissipation as described by Poiseuille's Law, decreasing the radius causes a very large increase in the pressure drop per unit length.

In our example, if we substitute $(0.5)r_a$ for r_b:

$$\frac{\Delta P_a r_a^4}{l_a} = \frac{2\Delta P_b r_b^4}{l_b}$$

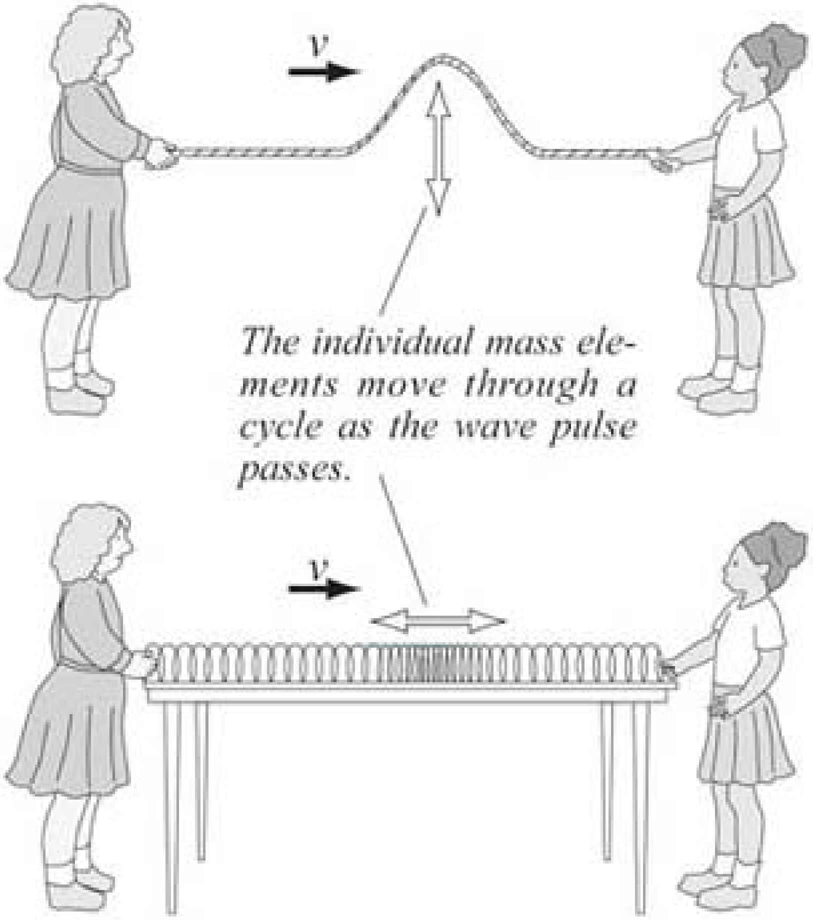
$$\frac{\Delta P_a r_a^4}{l_a} = \frac{2\Delta P_b (0.5\ r_a)^4}{l_b}$$

$$\frac{\Delta P_a}{l_a} = \frac{1}{8}\frac{\Delta P_b}{l_b}$$

A MAJOR CONSEQUENCE OF POISEUILLE'S LAW IS THAT IN THE CARDIOVASCULAR SYSTEM, THE NARROW VESSELS ARE MUCH SHORTER. IF NOT, THERE WOULDN'T BE PRESSURE REMAINING AFTER BLOOD FLOWS THROUGH THE CAPILLARIES FOR IT TO RETURN TO THE HEART.

Waves

Transverse and Longitudinal Waves



***A transverse pulse**. If the displacements associated with wave disturbances move in a direction perpendicular to wave motion, the wave is transverse.*

electromagnetic waves

***A longitudinal pulse**. If the displacements associated with wave disturbances move in a direction parallel to wave velocity, the wave is longitudinal.*

Sound waves

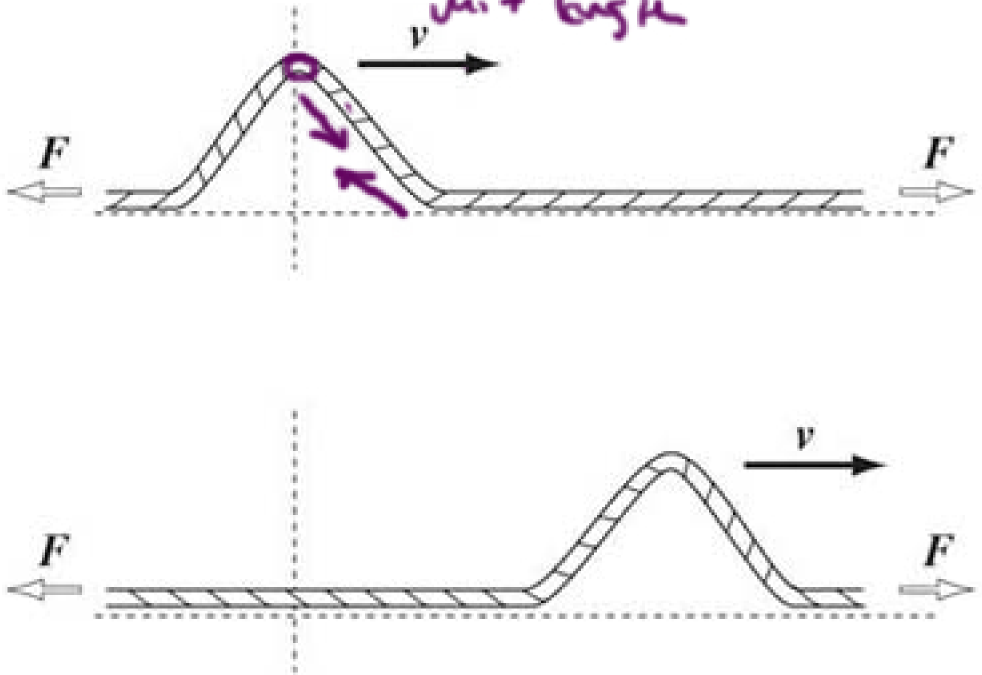
Speed of a Wave on a Stretched String

$$v = \sqrt{\frac{F}{\mu}}$$

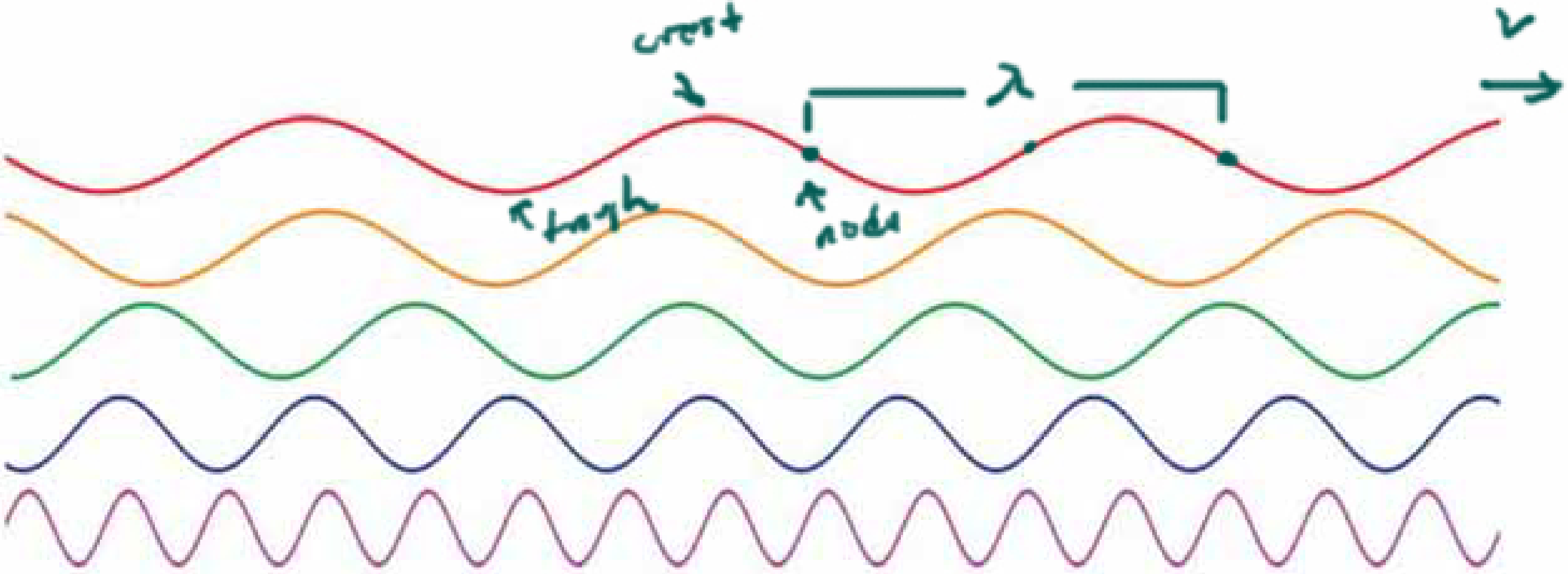
tension

mass/unit length

v = wave speed
F = tension
μ = mass per unit length



Harmonic Waves Repeat Themselves



λ : m, $\frac{m}{cycle}$

$k = m^{-1}$, $\frac{cycle}{m}$

T = s, s/cycle

$f = s^{-1}$, $\frac{cycle}{s}$, Hz

Harmonic Waves

$$\left(\frac{m}{cycle}\right)\left(\frac{cycle}{s}\right) = m/s$$

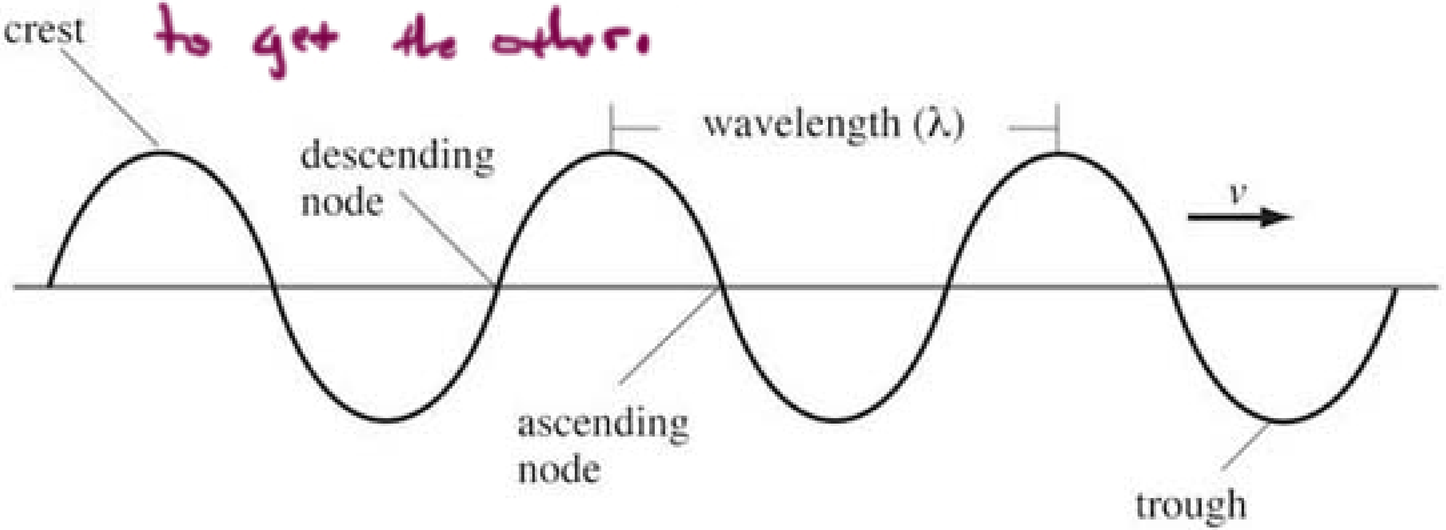
$$(\lambda)(f) = v$$

$$v = \lambda f$$

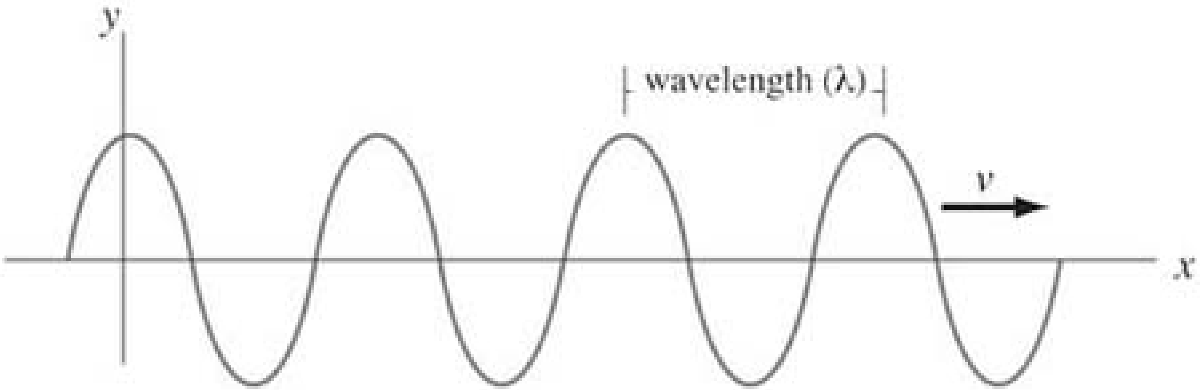
$$\lambda = \frac{v}{f} \qquad f = \frac{v}{\lambda} \qquad T = \frac{1}{f}$$

v = wave speed
λ = wavelength
f = frequency
T = period

Divide either λ or f into v to get the other.



The wavelength of a harmonic wave divided by its speed of propagation is equal to:



$$\frac{m/\text{cycle}}{m/s} = s/\text{cycle}$$

a. the frequency

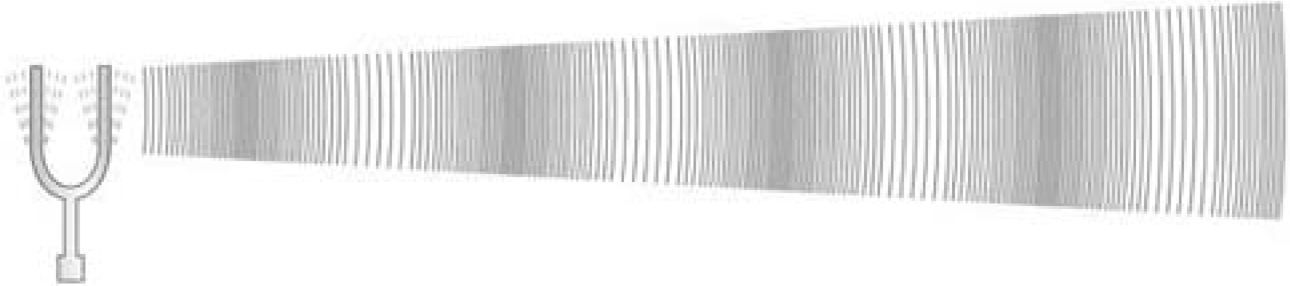
b. the angular frequency

c. the wave number

d. the period

A tuning fork produces an E note (frequency = 660 Hz). The wavelength is 0.5 m. At what speed do sound waves move through the air of this room?

$v = f\lambda$



a. 132 m/s

b. 165 m/s

c. 330 m/s

d. 1320 m/s

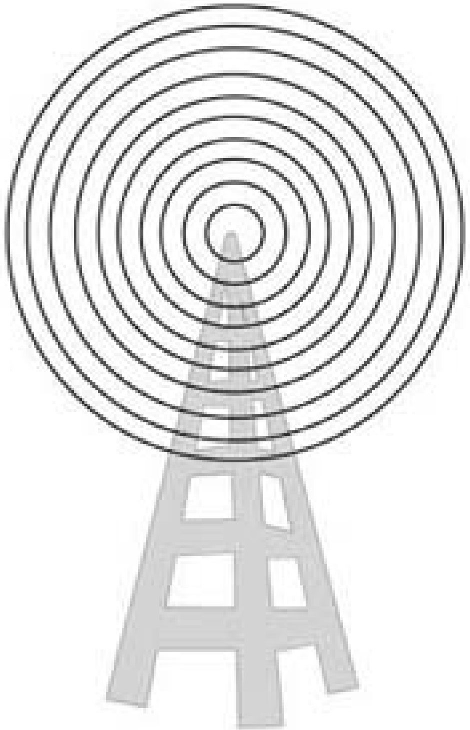
An FM radio station broadcasts at 100MHz on the dial. What is the wavelength of its signal?

a. 1.0×10^{-8} m

b. 0.33 m

c. 3 m

d. 100 m



$$\lambda = \frac{v}{f}$$

$$\lambda = \frac{3 \times 10^{8}\ m/s}{1 \times 10^{9}\ s^{-1}}$$

$$= 3m$$

Sound Waves

$v = \sqrt{\frac{F}{\mu}}$

analogous

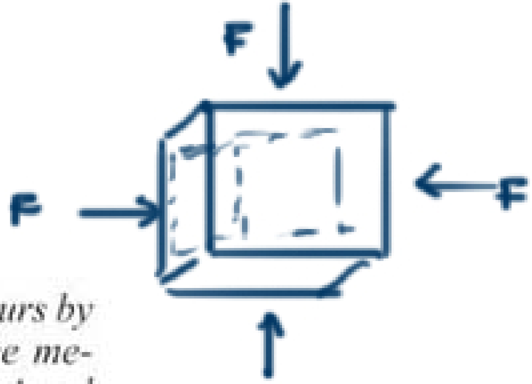
Bulk Modulus (stiffness)

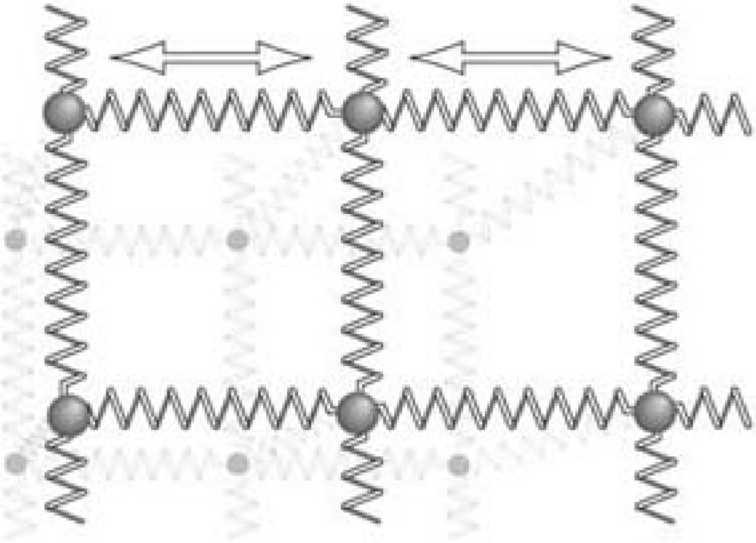
$$v = \sqrt{\frac{B}{\rho}}$$

inertia

v	=	speed of sound
B	=	bulk modulus
ρ	=	density

$$\beta = \frac{F/A}{-\Delta V/V_0}$$





Sound wave propagation occurs by means of the elasticity of the medium. Imagine a three dimensional matrix in which mass elements are connected by springs. Increasing the strength of the springs (bulk modulus) would increase the speed of waves through the medium. Increasing the mass of the elements (density) would slow the waves down.

elastic modulus $= \frac{\text{stress}}{\text{strain}}$

$$k = \frac{-F}{\Delta x}$$

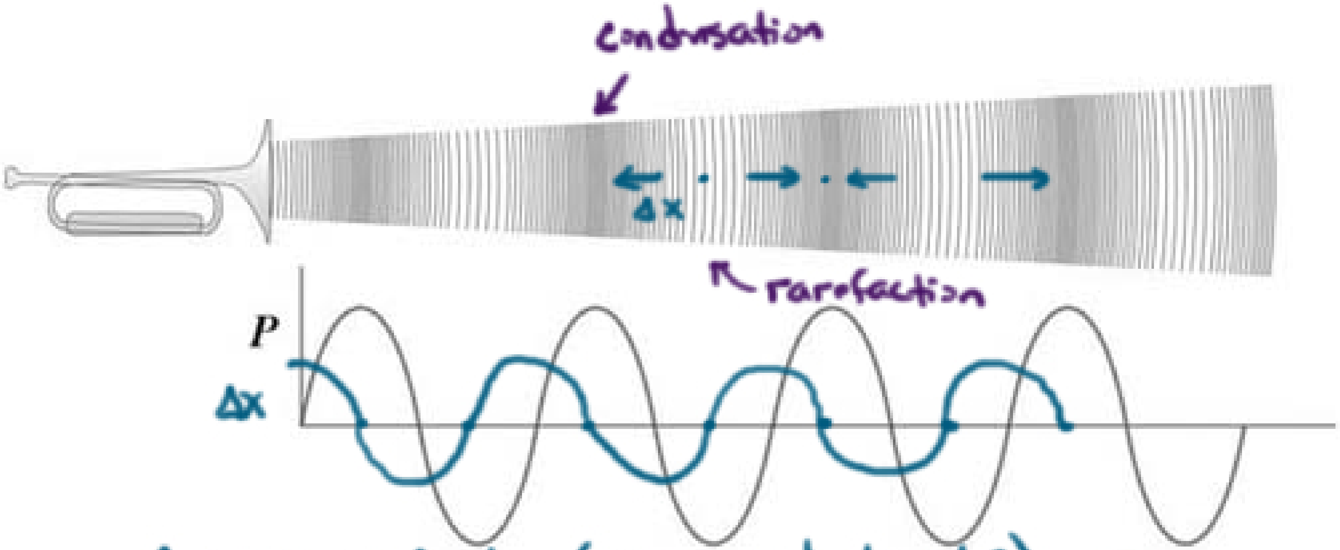
Which of the following is a true statement concerning sound waves?

a. Sound waves can pass through a vacuum.

b. The speed of sound does not depend on the medium of propagation.

c. Sound waves are longitudinal waves.

d. Sound waves cannot be reflected.



pressure antinodes (crests and troughs) are displacement nodes.

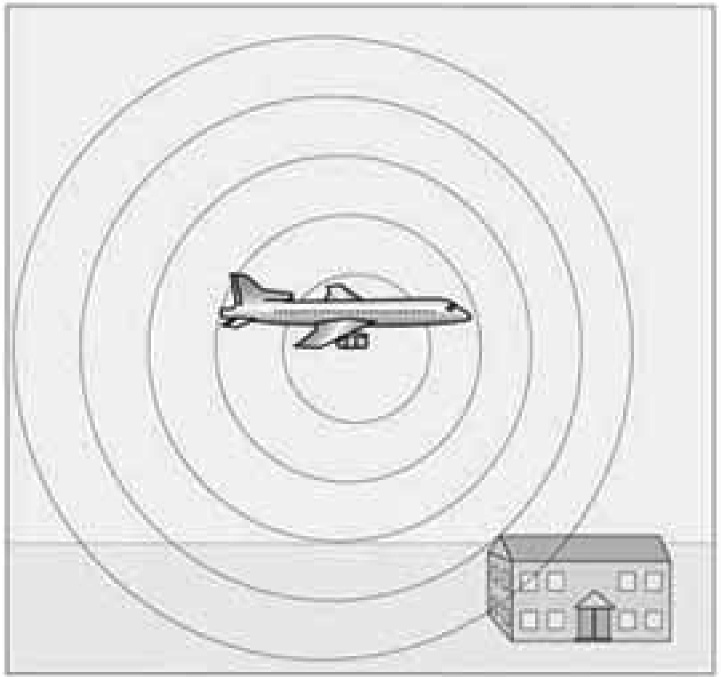
Loudness

original $10 \log \left(\frac{I}{I_0}\right)$

multiply intensity by A

new $= 10 \log A\left(\frac{I}{I_0}\right)$

$= 10 \log A + 10 \log \frac{I}{I_0}$



$$\beta = 10 \log \left(\frac{I}{I_0}\right)$$

Multiply I 10X
add 10dB

Multiply I 100X
add 20dB

Multiply I 1000X
add 30dB

β = loudness in decibels

I = intensity

I_0 = 10^{-12} W/m²

Intensity - W/m²

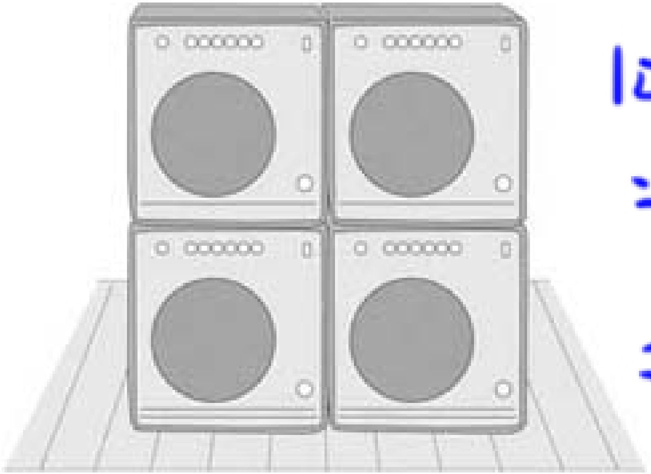
After judging a value of 120 dB a few meters in front of the stage to be insufficiently loud enough, a rock-and-roll band doubled the number of amplifiers in its stack. What was the loudness after the addition of the new amplifiers?

a. 123 dB

b. 130 dB

c. 144 dB

d. 240 dB



$10 \log I/I_0$

new

$10 \log 2I/I_0$

$= 10 \log I/I_0 + 10 \log 2$

$= 120\,dB + 3$

$= 123\,dB$

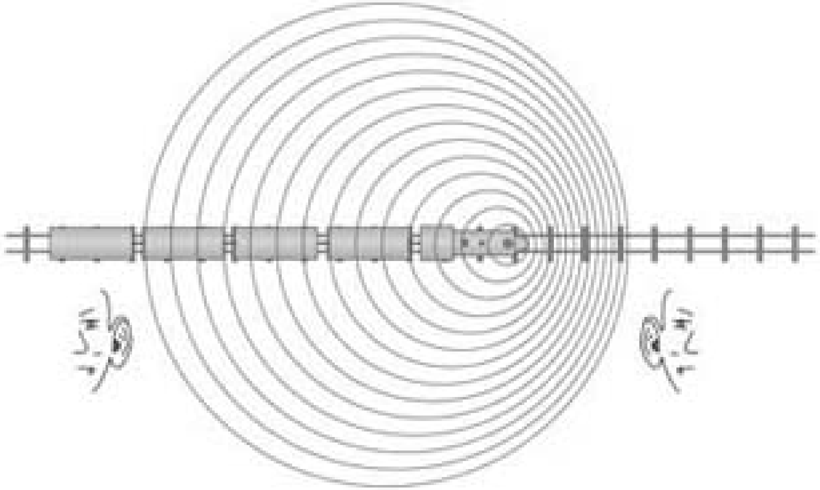
Use the signs that make sense

Doppler Effect

$$f' = f\left(\frac{v \pm v_0}{v \mp v_s}\right)$$

f' = observed frequency
f = source frequency
v = wave speed
v_O = speed of observer
v_S = speed of source

Doppler sonography



v blood flow

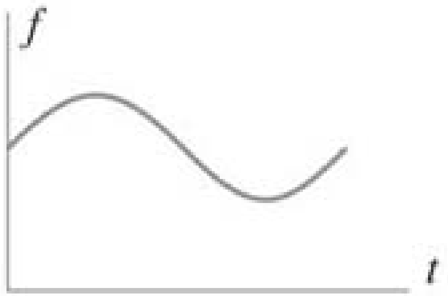
$$f' = f\left(\frac{v}{v \mp v_s}\right)$$

$$2t = v\,\Delta t$$

Because of the Doppler effect, the measured frequency of sound is greater for the observer the train is approaching than for the observer the train is leaving.

An astronomer discovers a planet orbitting a distant star, revolving once every 10 days. If her line of observation is within the orbital plane of the planet, which of the following curves best represents the observed frequency of the light from the planet as it undergoes one complete revolution around the star?

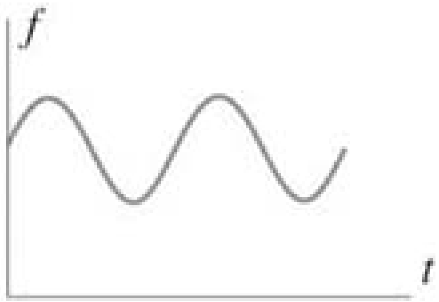
a.



c.

b.

d.



Standing Waves on a Stretched String

Standing waves which are possible have nodes at the pegs

$$\lambda_n = 2L,\ L,\ \frac{2L}{3},\ \ldots\ \frac{2L}{n}$$

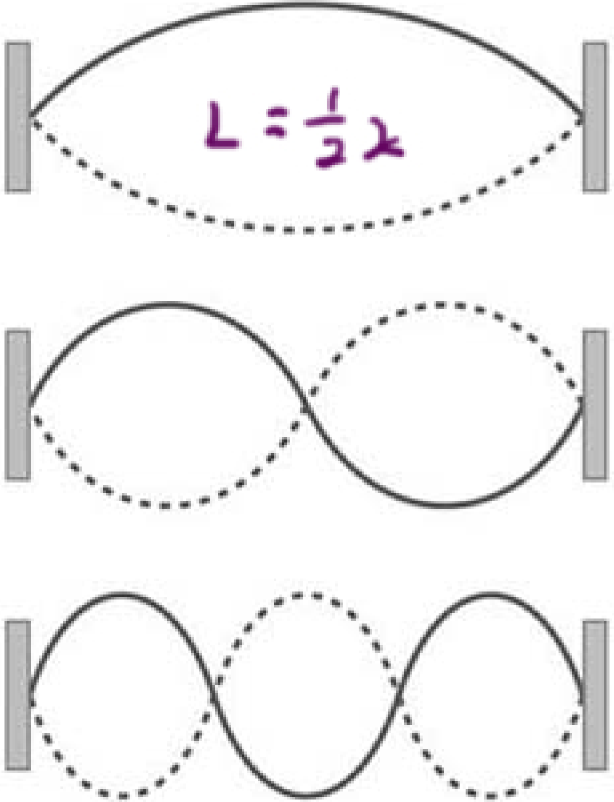
The wavelengths of the normal modes correspond to the possible waves with nodes at the fixed ends.

$$f = \frac{v}{\lambda_n} = \frac{n}{2L}v$$

It's a simple matter to move from wavelengths to frequency if you know the wave speed (deriving from the tension, F, and the mass per unit length, μ, of the string):

$$v = \sqrt{\frac{F}{\mu}}$$

λ_n = wavelengths of normal modes
L = length of string
n = 1, 2, 3, . . .
f = frequencies of normal modes
v = wave speed



$\lambda = 2L$

$\lambda = \frac{2L}{n}$

$n = 1, 2, 3 \ldots$

Standing Waves in Air Columns

Pipe Open at Both Ends

$$\lambda_n = 2L, L, \frac{2L}{3}, \ldots \frac{2L}{n}$$

$$f = \frac{v}{\lambda_n} = \frac{n}{2L}v$$

$(n = 1,2,3, \ldots)$

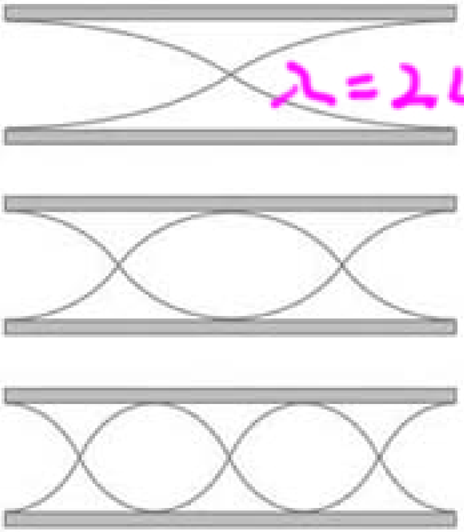
Pipe Closed at One End

$$\lambda_n = 4L, \frac{4L}{3}, \frac{4L}{5}, \ldots \frac{4L}{n}$$

$$f = \frac{v}{\lambda_n} = \frac{n}{4L}v$$

$(n = 1,3,5, \ldots)$

just like stretched string

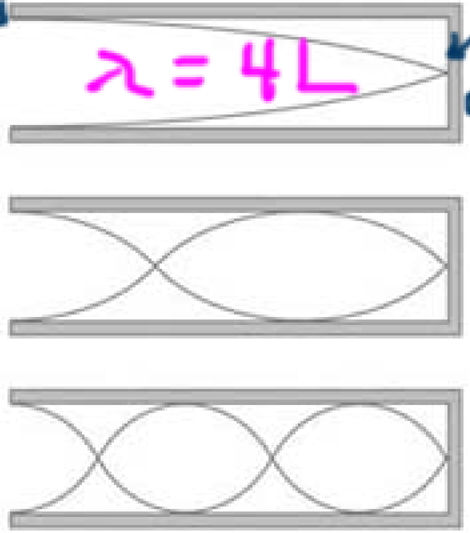


λ_n = wavelengths of normal modes

L = length of pipe

f = frequencies of normal modes

v = wave speed



$\lambda = \frac{4L}{n}$

$n = 1,3,5 \ldots$

Sound waves are represented as displacement waves

A flute is an example of a musical instrument that functions as a pipe closed at one end. What is the lowest musical note produced by a 0.75 m long flute (the speed of sound in this particular air is 330 m/s).

a. A (110 Hz)

b. B (248 Hz)

c. A (220 Hz)

d. E (660 Hz)

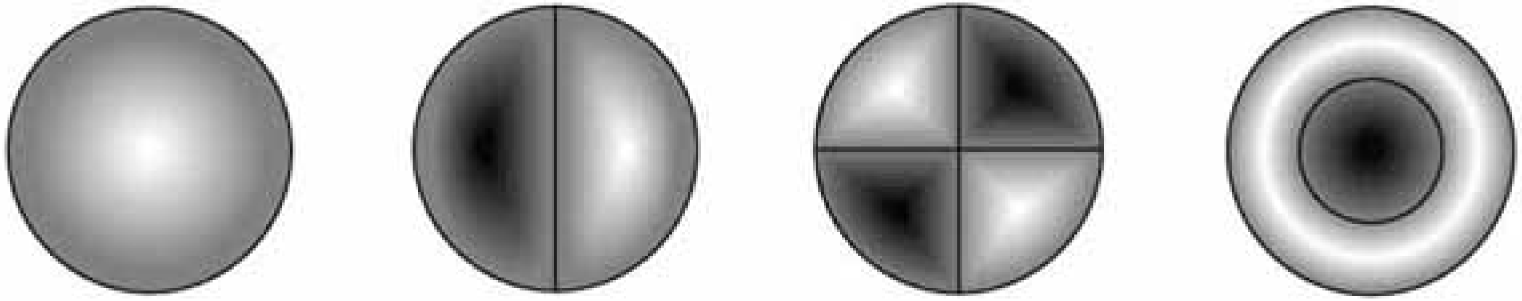
$\lambda = 4\,(0.75\,\text{m})$

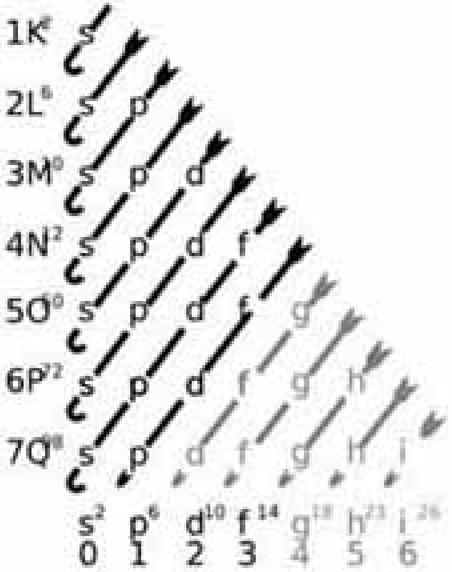
$= 3\,\text{m}$

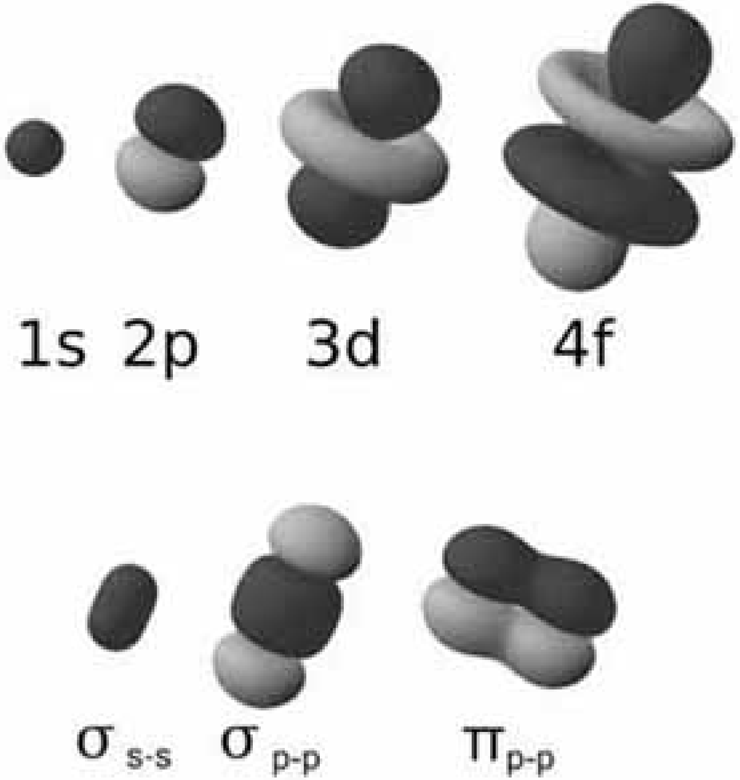
$v = 330\,\text{m/s}$

$f = \dfrac{330\,\text{m/s}}{3\,\text{m}}$

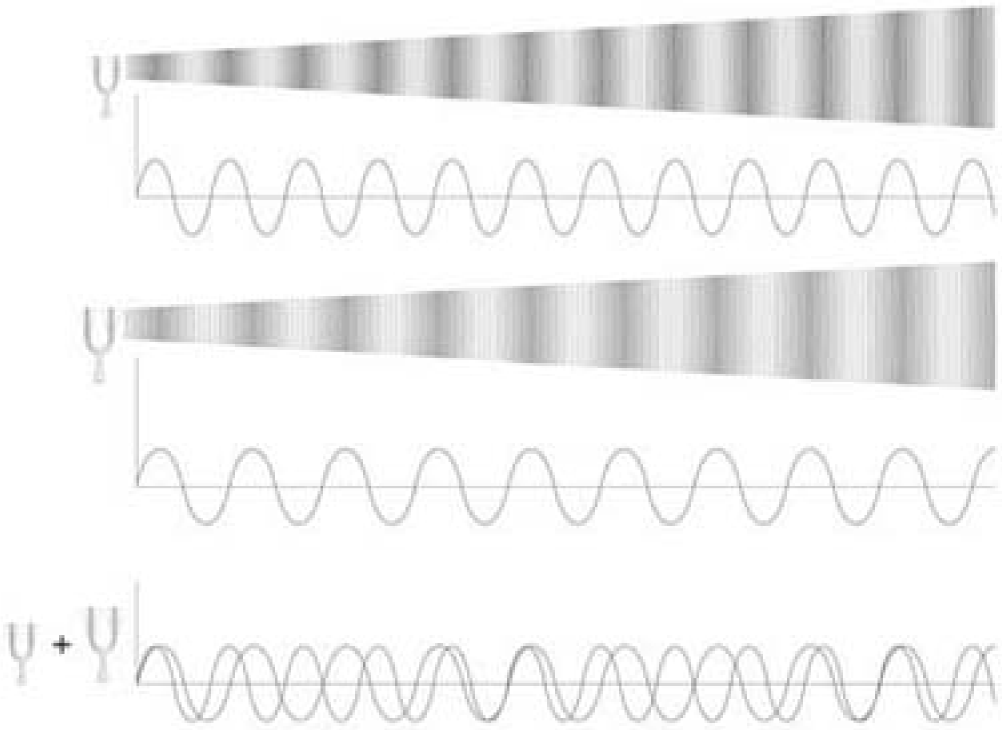
$= 110\,\text{Hz}$




1K
2L
3M
4N
5O
6P
7Q
s p d f g h i
0 1 2 3 4 5 6


1s 2p 3d 4f
σ s-s σ p-p π p-p

Beats



$$f_b = f_1 - f_2$$

f_b = beat frequency

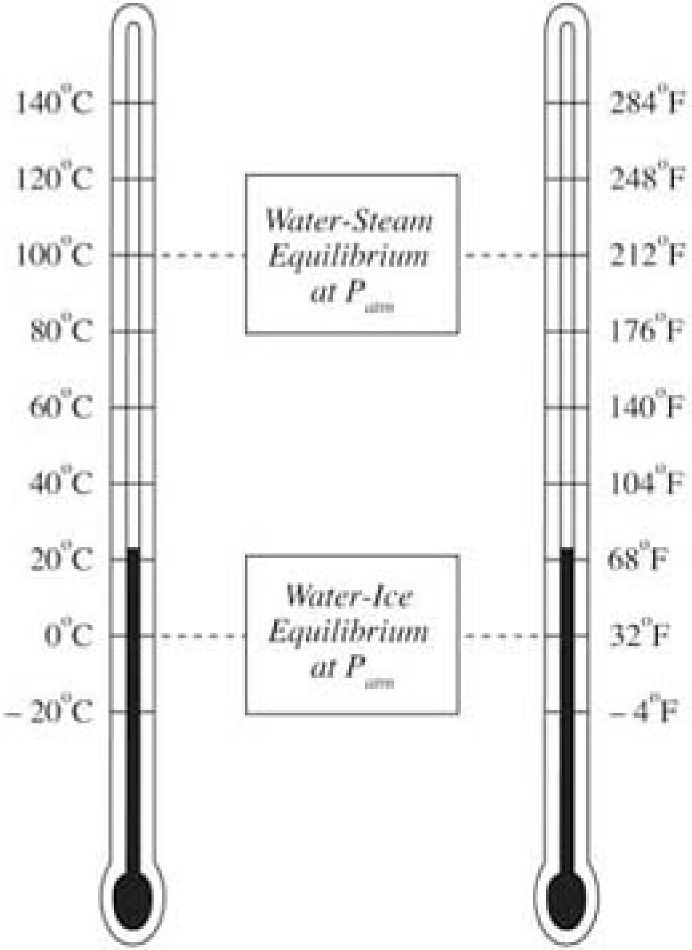
Beats are fluctuations in sound intensity produced when two tones nearly equal in frequency are sounded simultaneously.

Converting Celsius and Fahrenheit

$$T_c = \frac{5}{9}(T_f - 32)$$

$$T_f = \frac{9}{5}T_c + 32$$

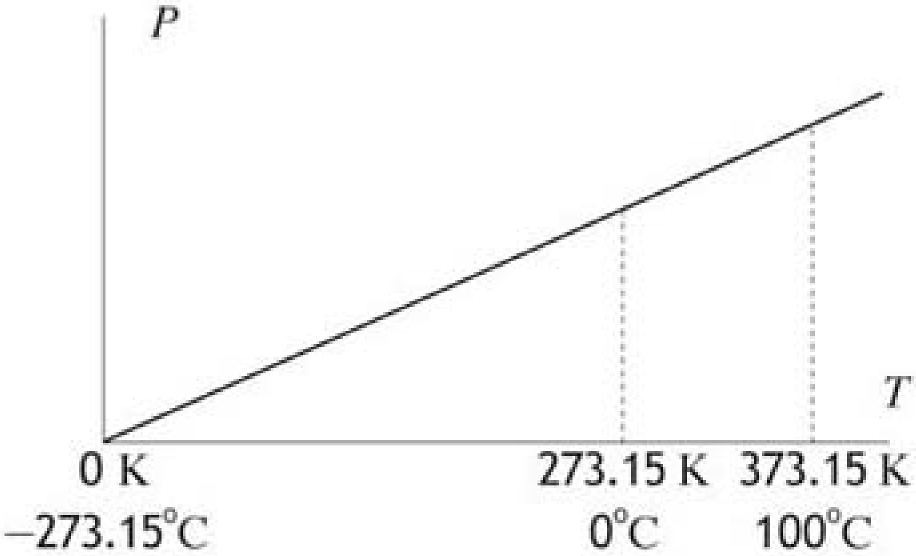
not on MCAT anyways



Kelvin Temperature

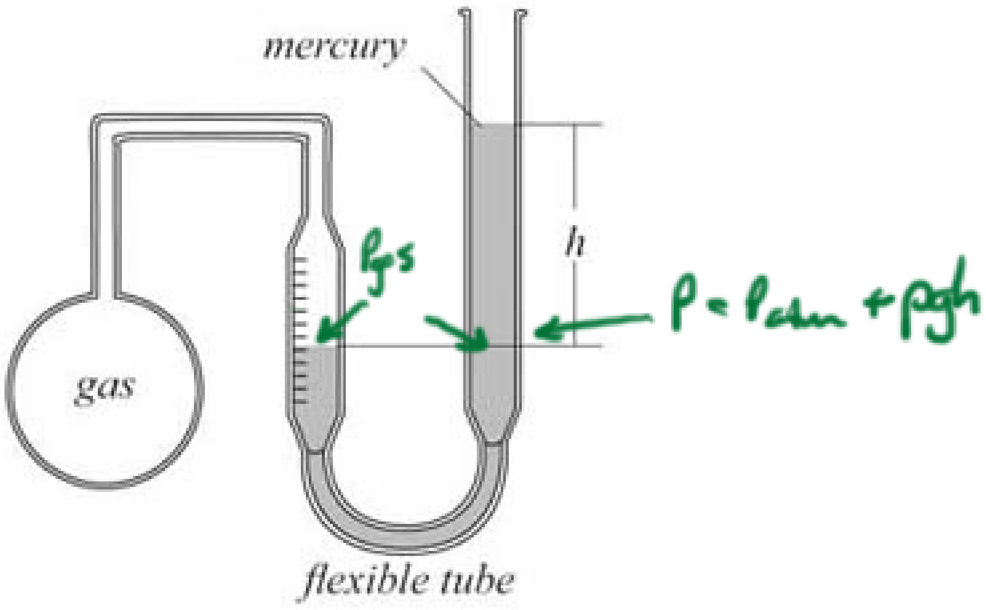
$$T = T_c + 273$$

convert to Kelvin!



Pressure-Temperature Graph for a Constant Volume Gas Thermometer

How does the constant volume gas thermometer pictured at right measure temperature?



a. It measures the pressure of the gas.

b. It measures changes in the volume of the mercury.

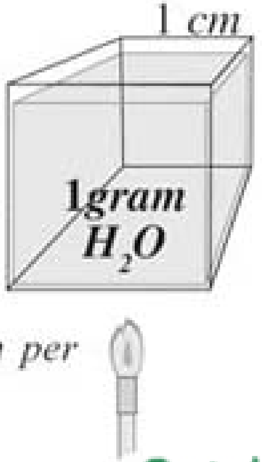
c. It measures the thermal expansion of the gas.

d. It measures the ratio of the density of the mercury to the density of the gas.

Specific Heat

$\frac{cal}{g \cdot °C}$ or $J/g \cdot °C$

$c_{H_2O} = \frac{1 cal}{g \cdot °C} = \frac{4.18 J}{g \cdot °C}$



Heat per gram per degree Celsius

1cal = 4.18 J

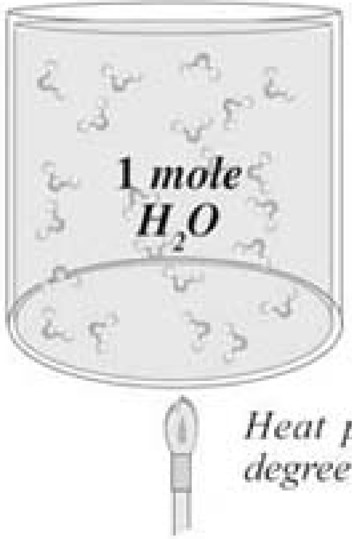
$(50g)\left(\frac{1 cal}{g \cdot °C}\right)(3°)$

$$Q = m\,c\,\Delta T = (150cal$$

Q	=	heat flow
m	=	mass
c	=	specific heat
ΔT	=	temperature change

Molar Heat Capacity

$\frac{cal}{mol \cdot °C}$ $J/mol \cdot °C$



6.02×10^{23} *molecules*

Heat per mole per degree Celsius

$$Q = n\,C\,\Delta T$$

Q	=	heat flow
n	=	number of moles
C	=	molar heat capacity
ΔT	=	temperature change

According to the *rule of Dulong and Petit* the molar heat capacity of metals with atomic weight above 35 is relatively constant (about 26 J / mole • °C). From the information presented, which of the metals in the table below has the lowest specific heat?

Element	Atomic Weight	Molar Heat Capacity at STP	
Ni	58.70	26.0	J / mole • °C
Ag	107.868	25.5	
Cd	112.40	26.0	
Pb	207.2	26.8	

a. Ni

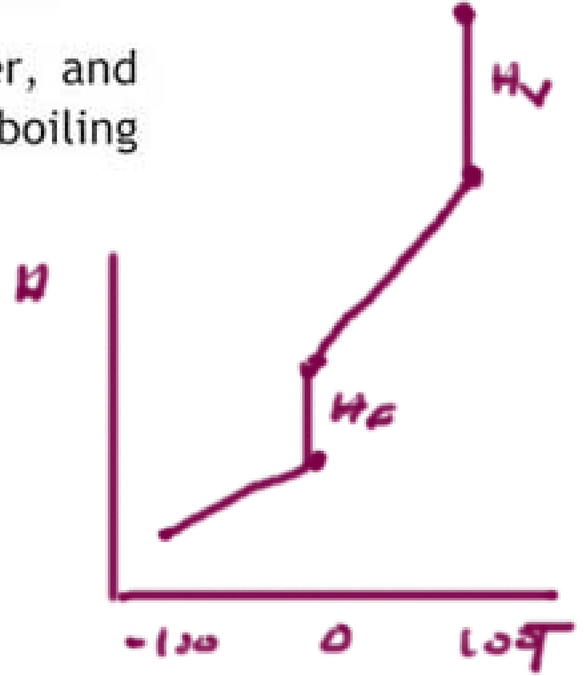
b. Ag

c. Cd

d. Pb

The table below gives the heat capacities of ice, liquid water, and steam as well as the heats of transformation for melting and boiling water (P = 1atm).

C_{ice} (cal/g · °C)	Latent Heat of Fusion (cal/g)	C_{water} (cal/g · °C)	Latent Heat of Vaporization (cal/g)	C_{steam} (cal/g · °C)
0.5	80	1	540	0.48



How much heat must be added to transform 1g of ice at -100°C into steam?

$Q = mc\Delta T$

a. 48 cal
b. 580 cal
c. 621.5 cal
d. 770 cal

The easiest path has four steps: 1) heating the ice from -100°C to 0°C; 2) melting the ice; 3) heating the liquid water from 0°C to 100°C; and finally, 4) boiling the water. The amount of heat which must be added for temperature change equals the product of the mass, specific heat and temperature change. For the phase changes, the amount of heat equals the product of the mass and the heat of transformation. Here are the computations for each of the four steps:

$$Q_{-100^\circ C \to 0^\circ C} = (1\ g)(.50\ \frac{cal}{g\ ^\circ C})(100^\circ C) = 50\ cal$$

$$Q_{fusion} = (1\ g)(80\ \frac{cal}{g}) = 80\ cal$$

$$Q_{0^\circ C \to 100^\circ C} = (1\ g)(1\ \frac{cal}{g\ ^\circ C})(100^\circ C) = 100\ cal$$

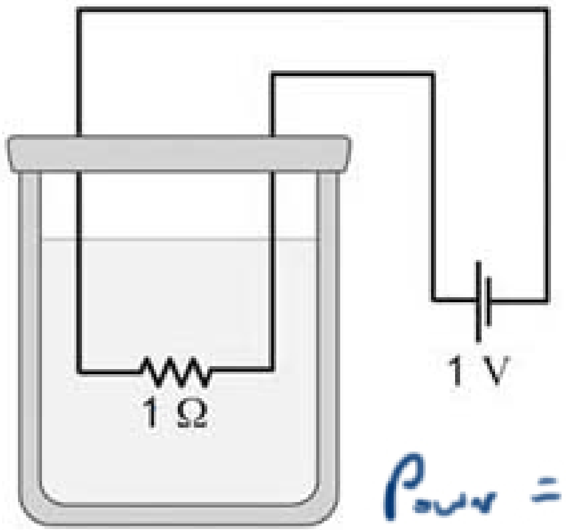
$$Q_{vaporization} = (1\ g)(540\ \frac{cal}{g}) = \underline{540\ cal}$$

$$sum = 770\ cal$$

THIS IS A VERY COMMONLY OCCURING TYPE OF PROBLEM. (ALTHOUGH THE COMPUTATIONS HERE ARE SUPPOSED TO BE EASY ENOUGH TO DO IN YOUR HEAD, IT'S A GOOD IDEA IN A TEST ENVIRONMENT TO WRITE THE COMPUTATIONS DOWN TO AVOID MISTAKES.

The Dewar flask at right contains 100ml of water at 25°C.

After a 1 volt (1 joule per coulomb) battery begins to deliver 1 ampere (1 coulomb per second) of current through the resistance immersed in the water, approximately how long does it take the water temperature to reach 35°C?



$c_{H_2O} = \frac{1\ cal}{g\ °C}$

$Q = (100g)(\frac{1\ cal}{g\ °C})(10°C)$

$= 1000\ cal$

$P_{owr} = 1\ J/s$

$P = VI$

$1000\ cal = 4200\ J$

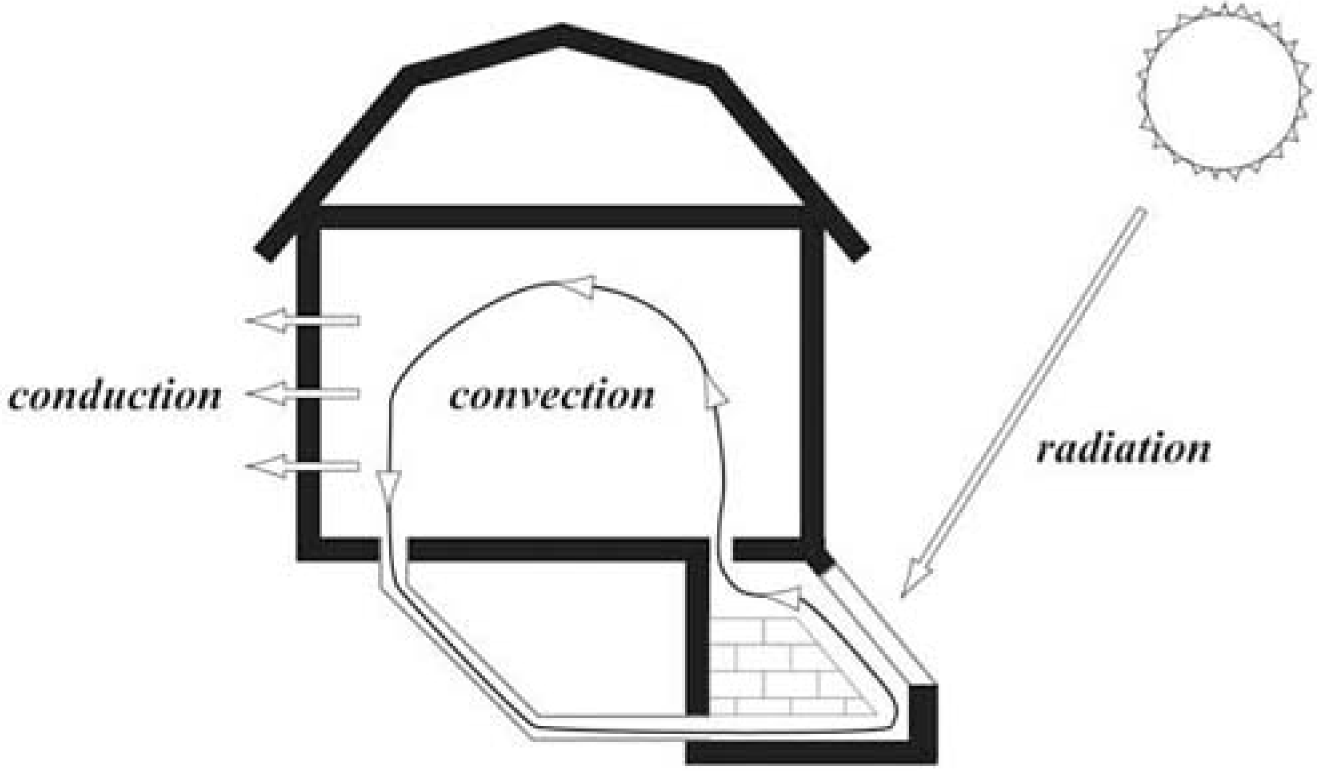
a. 10 seconds

b. 32 seconds

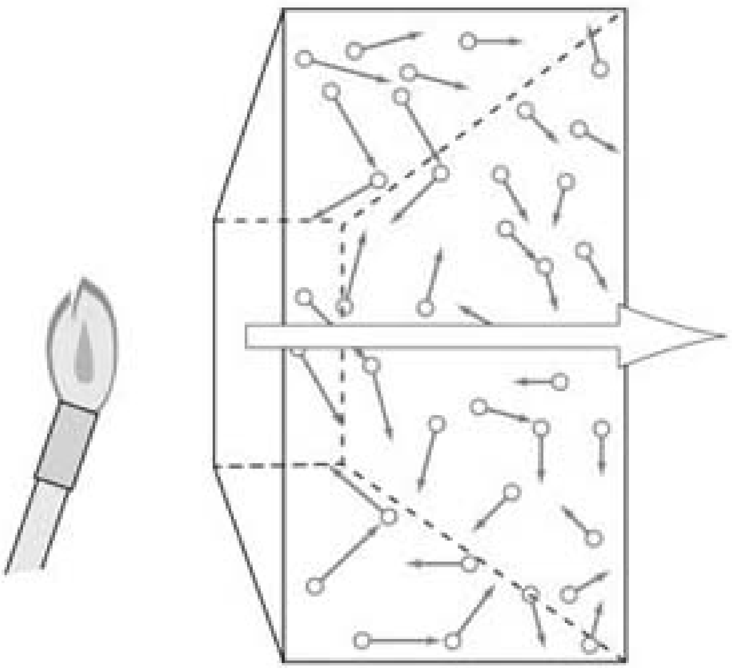
c. 1000 seconds

d. 4200 seconds (circled)

Three Modes of Heat Transmission



Transmission of Heat by Conduction

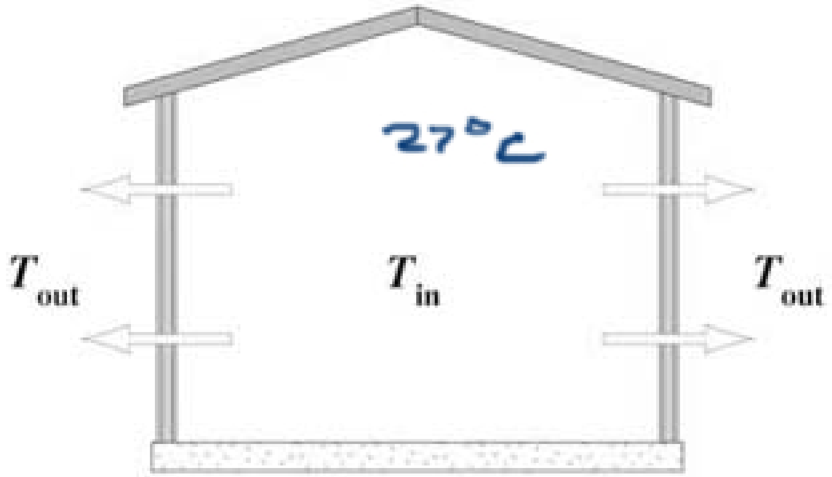


$$\frac{Q}{t} = K\,A\,\frac{\Delta T}{\Delta x}$$

Q	=	heat flow
t	=	time
K	=	thermal conductivity of material
A	=	cross-sectional area
ΔT	=	temperature difference across the conductor ($T_2 - T_1$)
Δx	=	conductor thickness

When warmer (faster) molecules collide with cooler (slower) molecules, the warmer molecules transfer part of their energy to the cooler molecules. Conduction of heat is occuring.

Night or day, the interior of a house is maintained at a constant temperature of 27°C. During the day, the outside temperature is 17°C. At night, the outside temperature is 7°C. What is the approximate percentage increase in the rate of heat lost by conduction through the walls of a house at night versus the day?



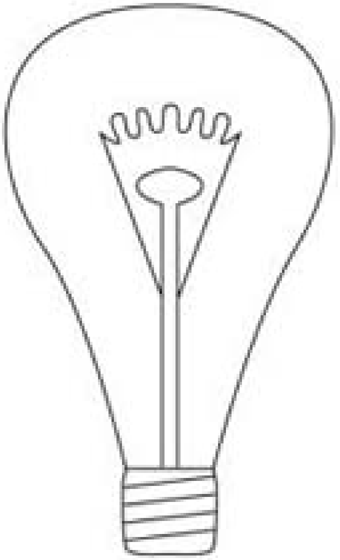
17°C day

7°C night

$$\frac{Q}{t} = kA\frac{\Delta T}{\Delta x}$$

a. 3% b. 9% c. 50% d. 100%

Transmission of Heat by Radiation - Stefan's Law



The tungsten filament (ε = 0.4) of a typical 100W bulb has a surface area of 40mm² and an operating temperature of about 3200K.

4th power! in Kelvin!

$$\frac{Q}{t} = A\varepsilon\sigma T^4$$

emissivity

Q	=	heat (light) emitted
t	=	time
A	=	surface area of emitter
ε	=	emissivity
σ	=	Stefan-Boltzmann constant (5.7 X 10^{-8} W/m² · K⁴)
T	=	emitter absolute temperature

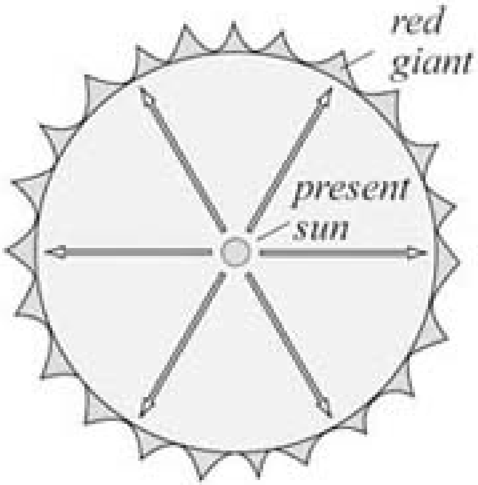
A good absorber is a good emitter

A good reflector is a poor emitter.

$\varepsilon = 1$ for a perfect blackbody

only absorbs and emits

Scientists predict that in approximately five billion years the energy from a changing hydrogen fusion dynamic within our sun will push the outermost layers of the star outward. Expanding and cooling, the sun will become a red giant, perhaps even engulfing the earth. If its temperature decreases from 6000K to 3000K and its radius undergoes a 40 fold increase, what will be the resulting change in the luminosity of the Sun? (luminosity is the rate of total light emission)



Growth of the sun into a red giant will occur in approximately five billion years.

$$\frac{Q}{t} = A\varepsilon\sigma T^4$$

$\frac{1}{2}T \rightarrow \frac{1}{16}\times$ change

$40r \rightarrow 1600\times$ change

a. 16 fold decrease

b. 80 fold decrease

c. 20 fold increase

d. 100 fold increase

$A = 4\pi r^2$

Engineers designed the Apollo capsule/command module to be constructed with a silvered exterior to control heat exchange with the environment during space travel. Which of the following were among the effects of this design feature on heat exchange?

a. Maximizing the absorption of energy from the surroundings

b. Minimizing the radiation of energy to the surroundings

c. Minimizing convection currents within the vehicle

d. Maximizing conductive diffusion of heat along the vehicle

Macrostate Functions

Pressure -

F/A $N/m^2 = 1$ Pascal

1 atm = 101,000 Pa

1×10^5 Pa

= 760 torr

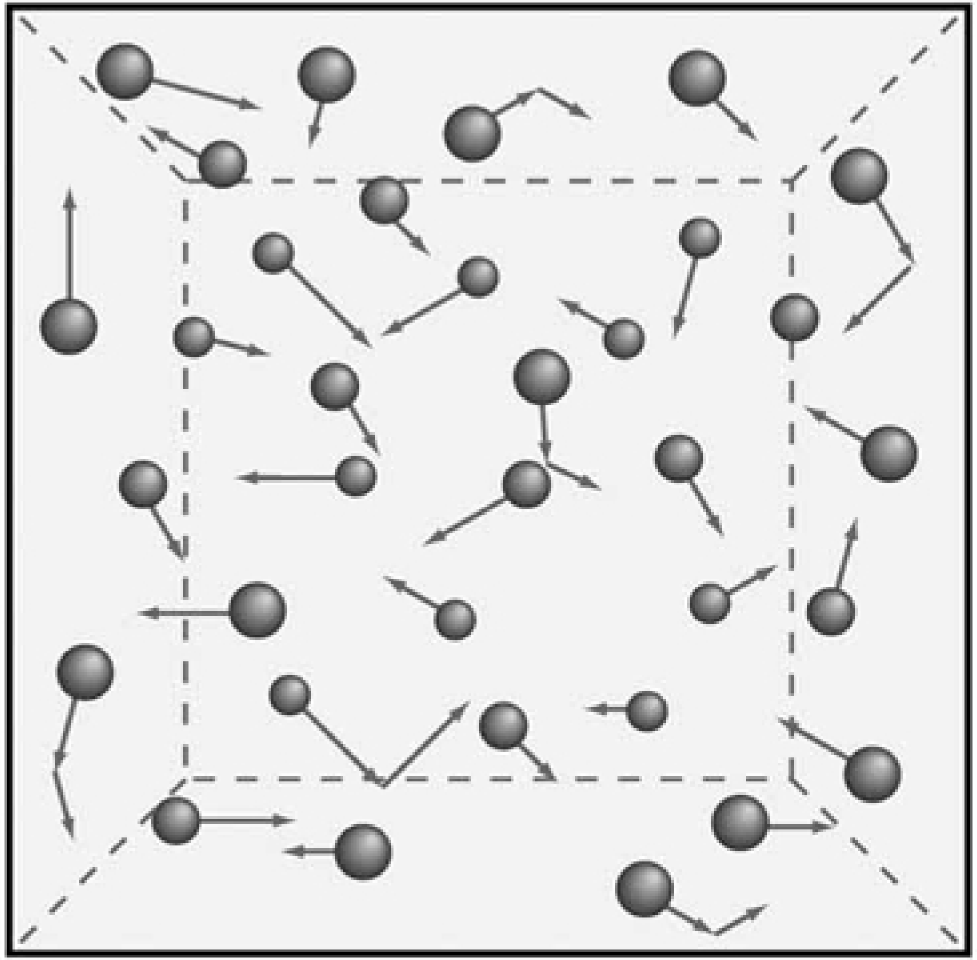
Volume -

$m^3 = 1000$ L

$L = 10^{-3} m^3$

Temperature

$\frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$



Ideal Gas

& Kinetic Theory

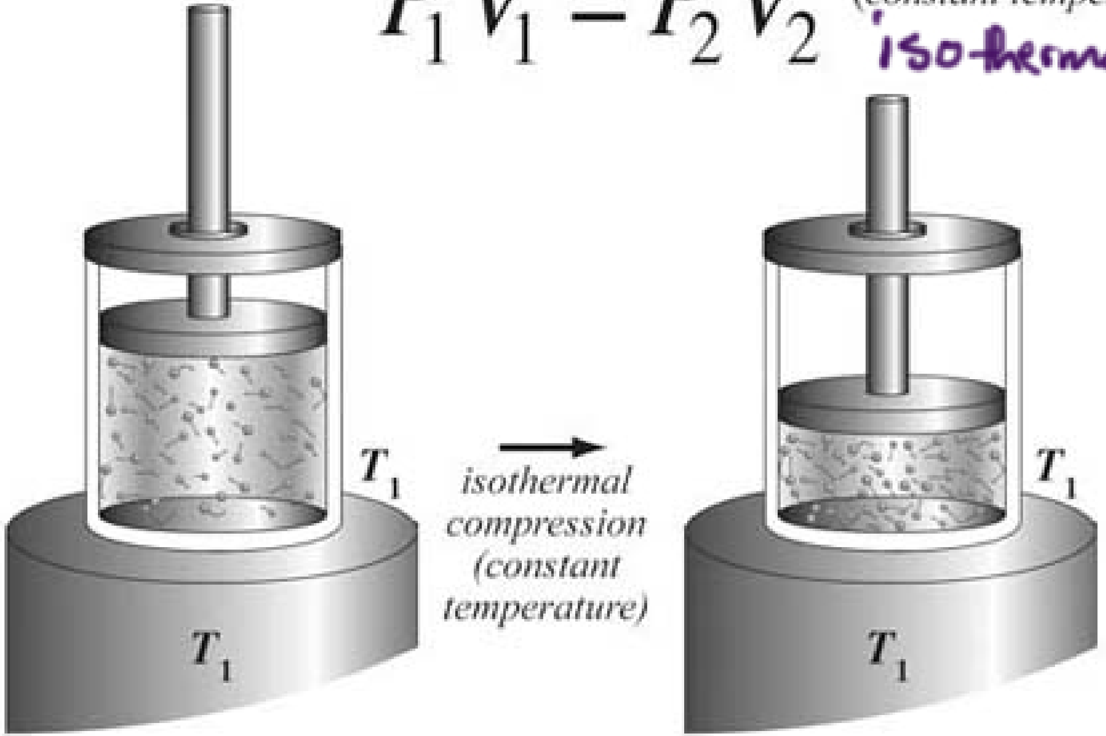
+ 1st law of thermodynamics

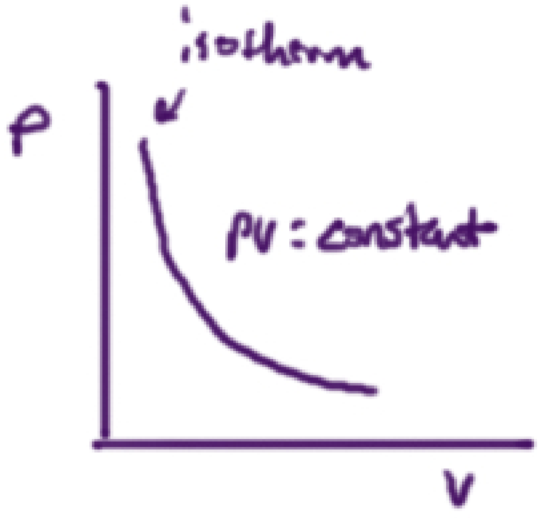
- point masses
- elastic collisions
- no action-at-a-distance forces

Boyle's Law

$$P_1 V_1 = P_2 V_2$$ *(constant temperature)*

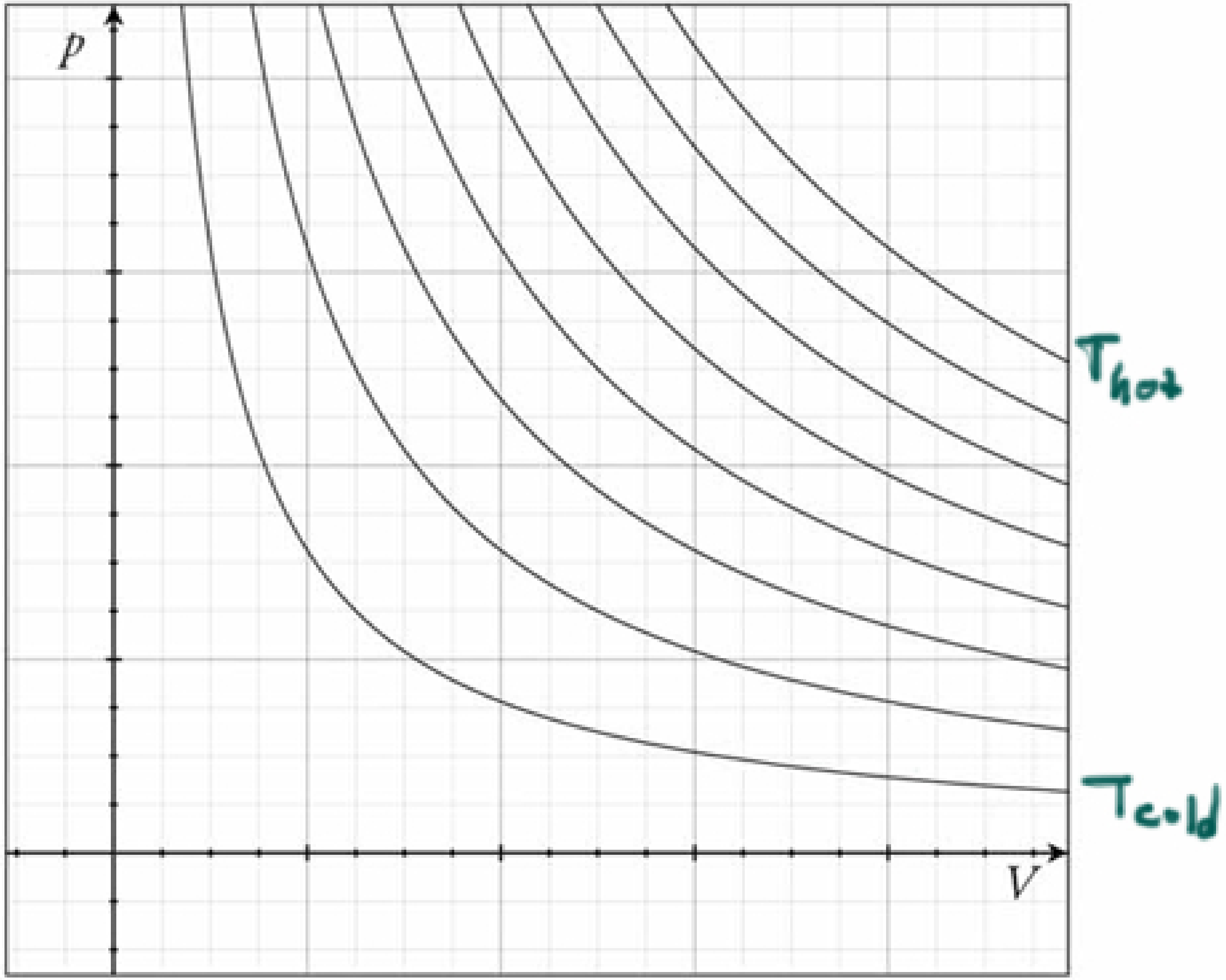
isothermal





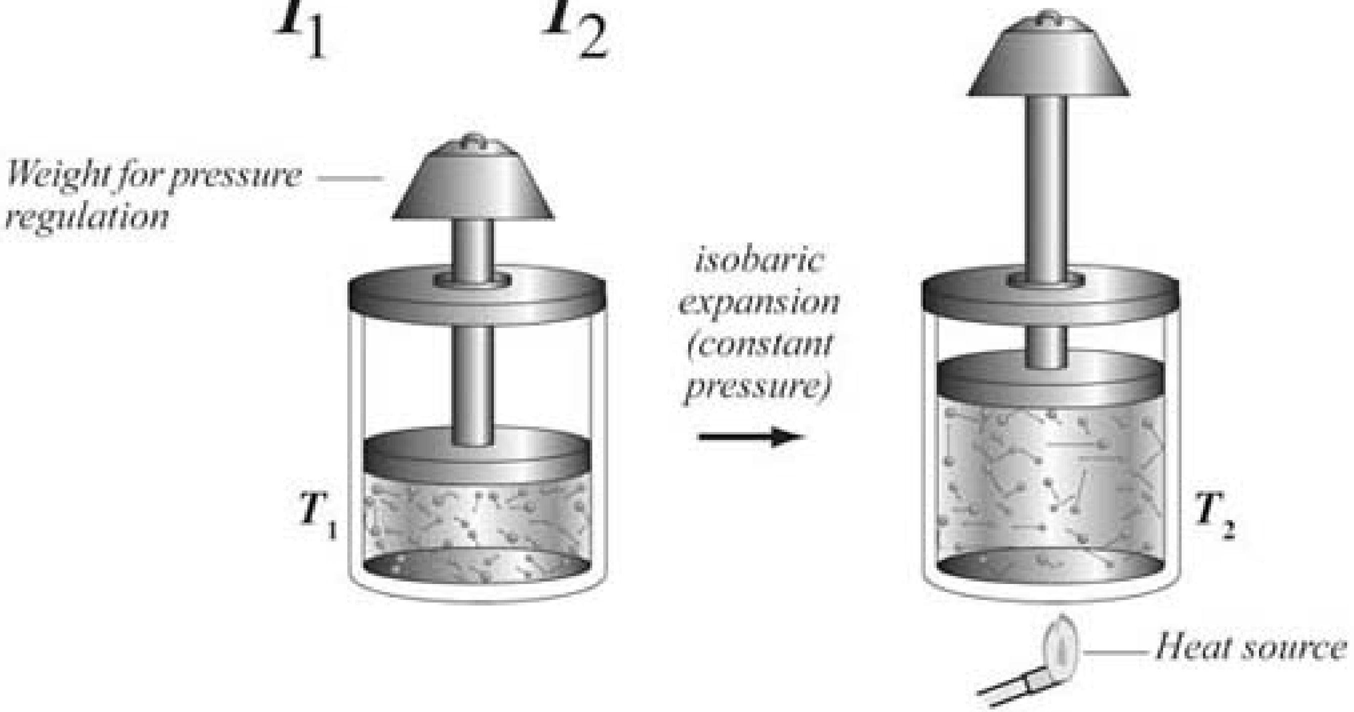
Thermal equilibrium with the heat sink allows the gas to be compressed at constant temperature, isothermally. With constant temperature, Boyle's Law applies. The pressure and volume are inversely proportional (PV is constant). Pressure increases as volume decreases.

isotherms



Charles' Law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$ *(constant pressure)* isobaric



$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

combined gas law

Heating a gas makes its particles move faster. Collisions are stronger. Therefore, to exert the same pressure, the particles must be more spread out. The volume must have increased.

Constant P

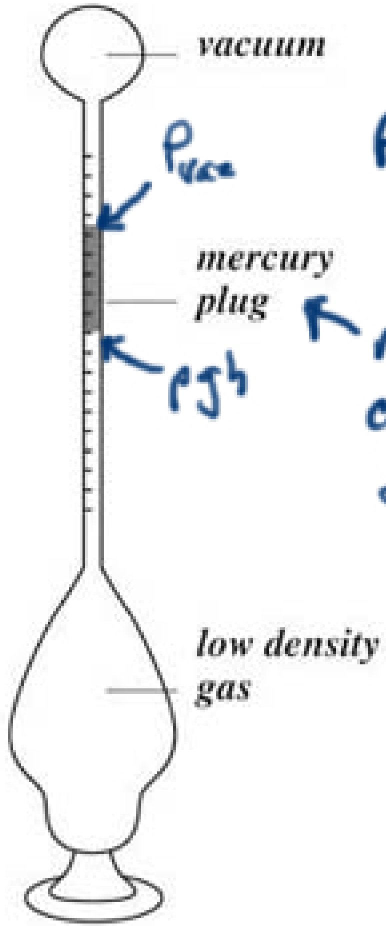
How does the thermometer at right measure temperature?

a. It measures the pressure of the gas.

b. It measures changes in the volume of the mercury.

c. It measures the volume of the gas.

d. It measures the ratio of the density of the mercury to the density of the gas.



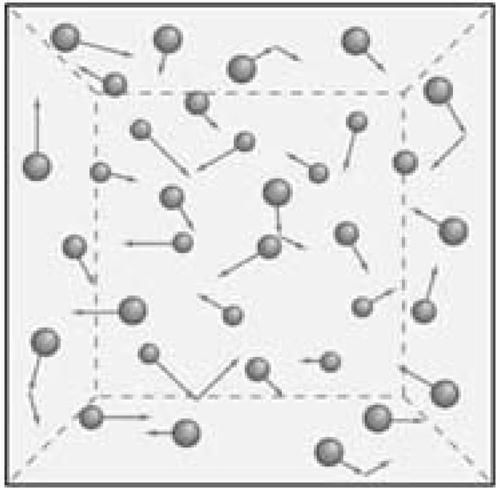
Charles' Law thermometer

Any two of P, V, T specify the state of a gas

The Ideal Gas Law • state equation of an ideal gas

$$PV = nRT$$

P	=	pressure
V	=	volume
T	=	temperature
n	=	# of moles of gas
R	=	ideal gas constant
		[8.31 J/mole · K] ← 8
		[0.082 liter · atm/mole · K] ← .08



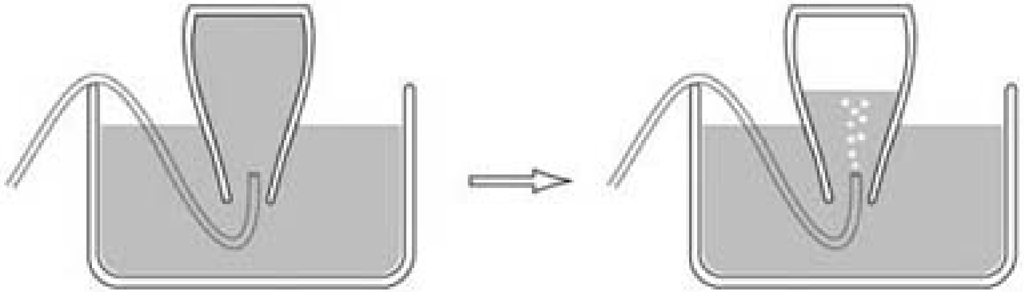
1 mole of an ideal gas occupies 22.4 liters at STP.

STP – 273 K (standard T)

298 K – standard state T

1 atm P

To serve as an apparatus for collecting gaseous substances a flask is completely filled with water and inverted with its mouth submerged within a larger container of water.



$PV = nRT$

$V = \frac{n}{P} RT$

Student A collects methane gas (CH_4) in this manner, and student B collects propane gas (C_3H_8). After each has collected one gram of substance:

a. the gaseous phase in student A's flask has greater volume

b. the gaseous phase in student B's flask has greater volume

c. the volume of the gaseous phases of both flasks are equal

d. the gaseous phase in student B's flask has greater pressure

The Temperature of an Ideal Gas Depends on the Average Translational Kinetic Energy of the Particles

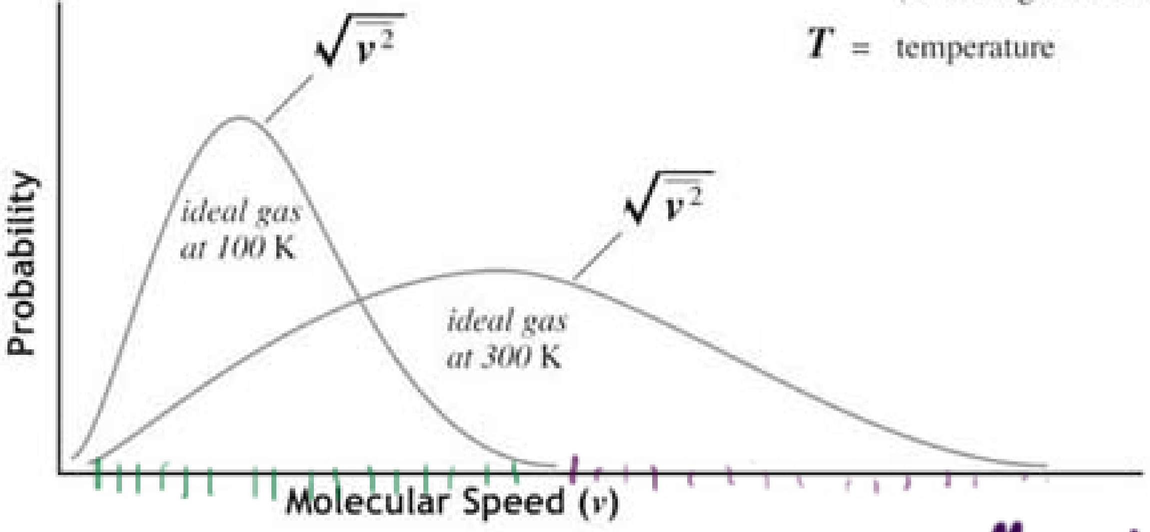
$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$$

m = mass

$\overline{v^2}$ = average square speed

k = Boltzmann's constant (R / Avogadro's number)

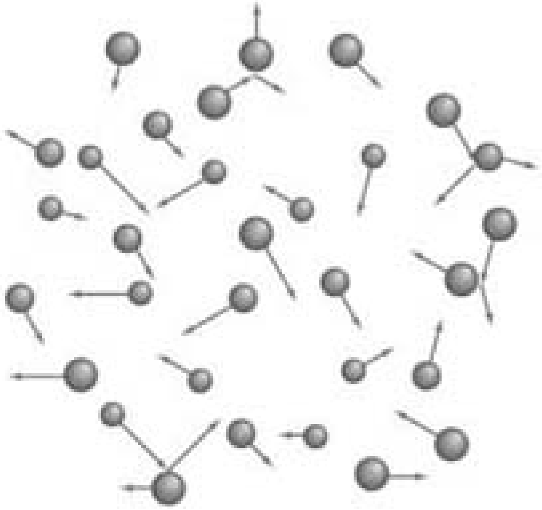
T = temperature



Maxwell Boltzmann Distribution

The difference in the velocity distribution curves for ideal gas particles at 100 K and 300 K shows the dependence of the average translational kinetic energy of the particles on temperature.

The Internal Energy of an Ideal Gas Depends on Temperature



$\frac{U}{N} = \frac{3}{2}kT$

$\frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$

$$U = \frac{3}{2}NkT$$

U = internal energy
N = number of molecules
k = Boltzmann's constant
= R / Avogadro's number
T = temperature

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

n = moles of gas
R = ideal gas constant

RMS Particle Speed Is Inversely Proportional to the Square Root of Particle Mass *(for a given temperature)*

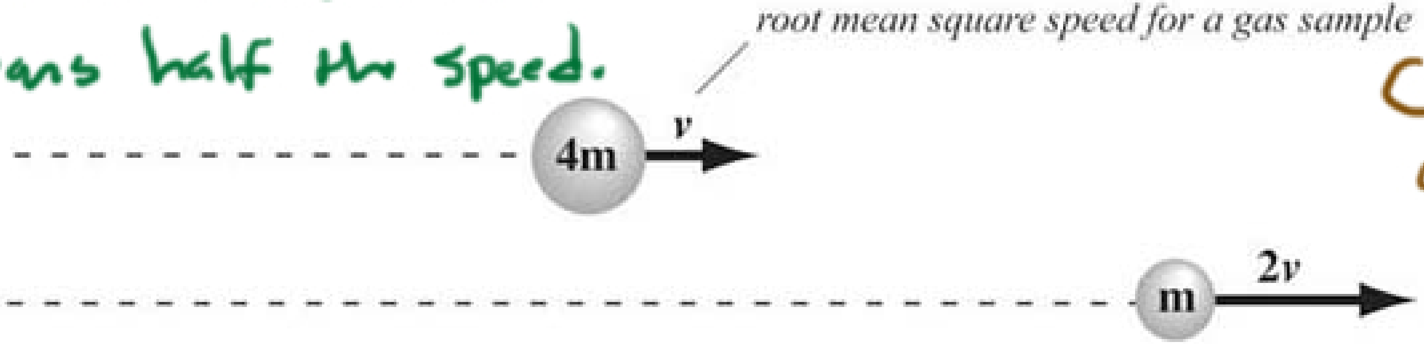
$$\frac{1}{2} m_A \bar{v}_A^2 = \frac{1}{2} m_B \bar{v}_B^2$$

$$\frac{\bar{v}_A}{\bar{v}_B} = \frac{\sqrt{m_B}}{\sqrt{m_A}}$$

m = mass
$\bar{v}$ = root mean square speed (square root of average square speed)

Four times the mass means half the speed.

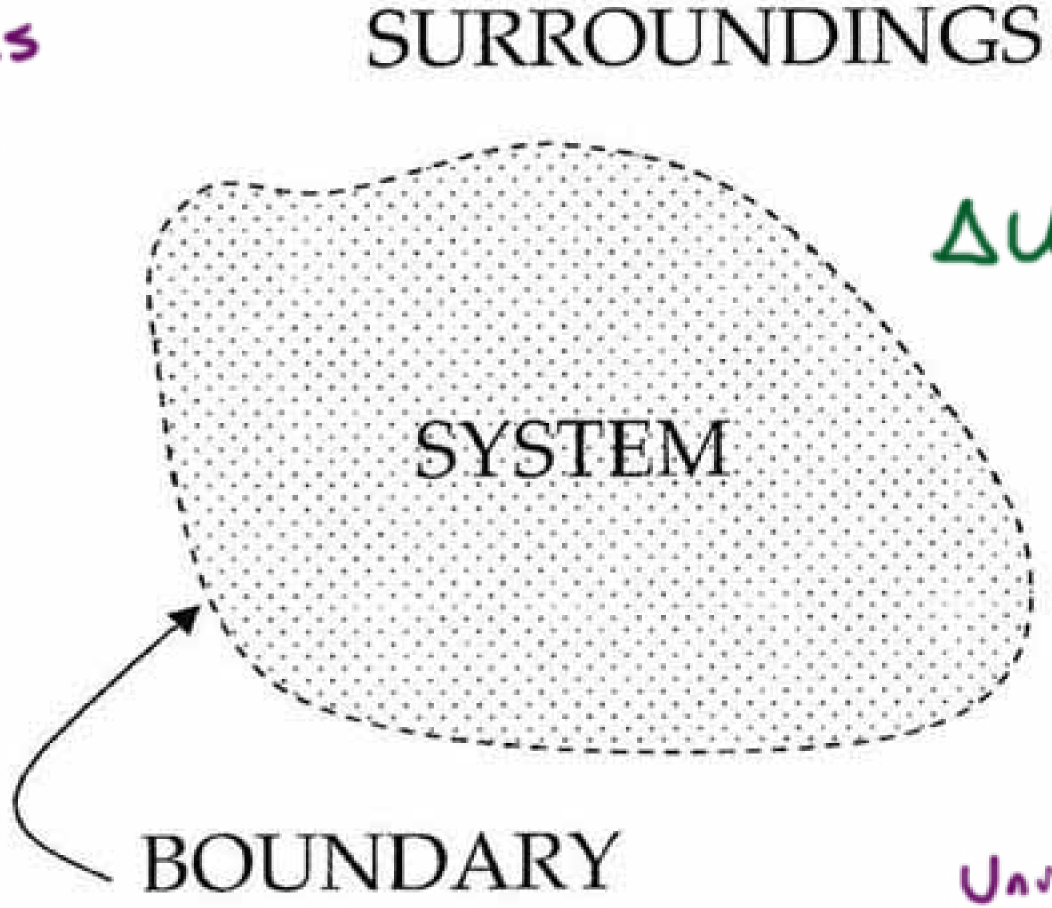
Graham's Law of effusion



'Average' (root mean square) speed is inversely proportional to the square root of molecular mass. For two samples of ideal gas at the same temperature, if the molecules of one gas are four times larger, the root mean square speed is half as great.

1st Law of Thermodynamics

- Conservation of energy



heat flow → Q

$$\Delta U = Q - W$$

thermodynamic work → W

$$P\Delta V$$

Universe = System + Surroundings

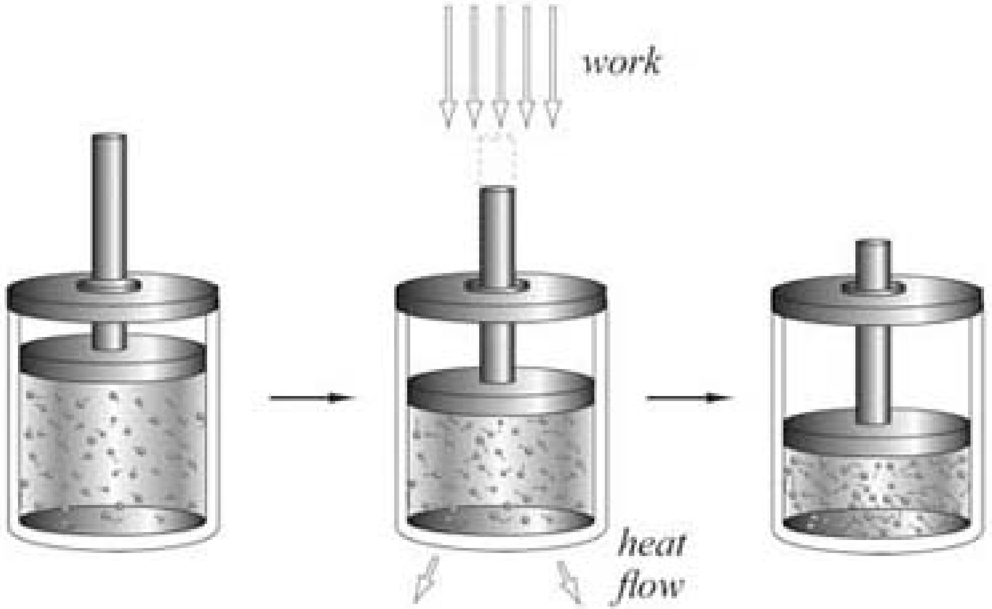
The Universe

The First Law of Thermodynamics

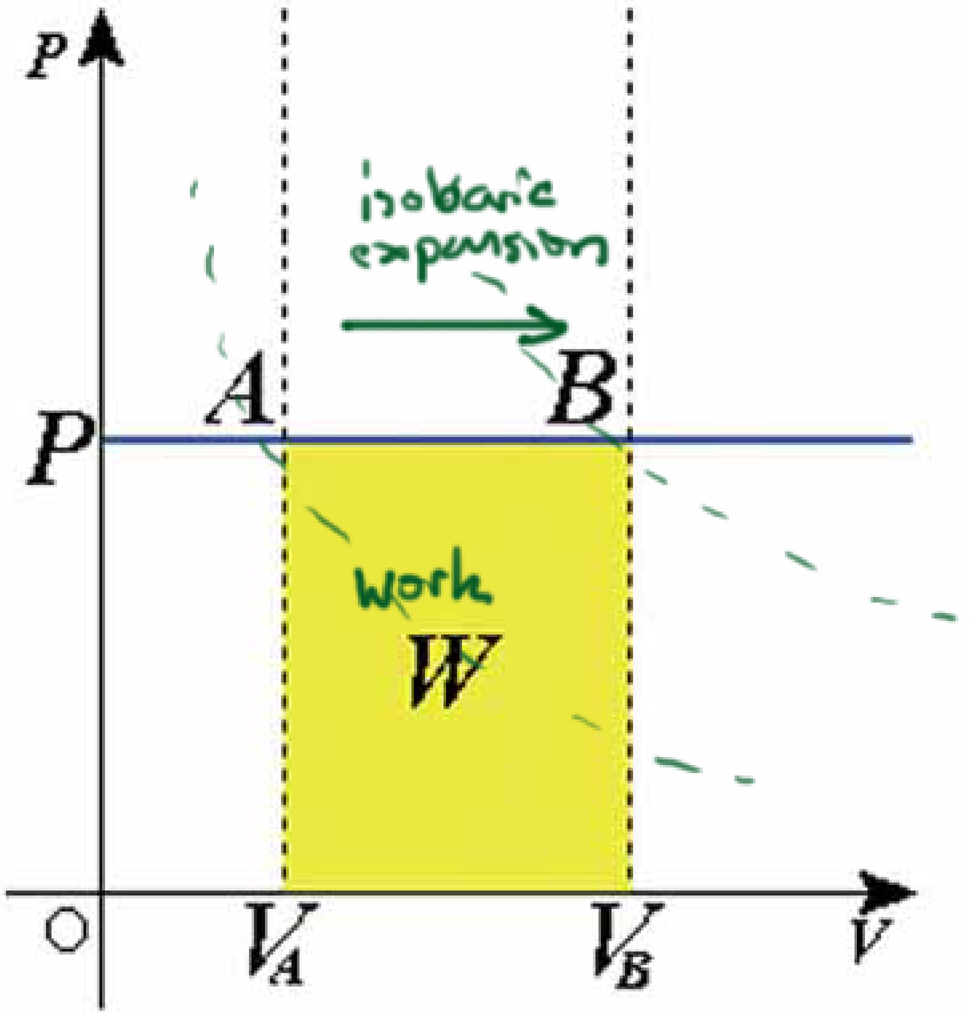
$$\Delta U = Q - W$$
$$= Q - P^{*}\Delta V$$

ΔU = internal energy change
Q = heat flow
W = macroscopic work

P^{*} = constant pressure
ΔV = volume change

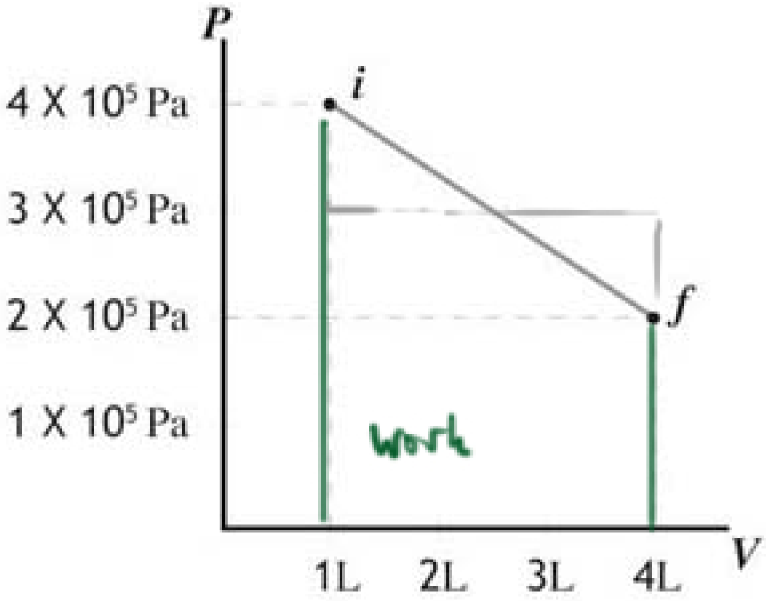


Internal energy change results from the combination of heat flow and work between the system and its surroundings. In this example, the internal energy of our ideal gas system became greater (the particles are moving faster in the final state) because more energy entered the system through work than departed the system as heat flow.



P
isobaric
expansion
A
B
P
work
W
O
V_A
V_B
V

The straight line on the graph shows the path between the initial and final states in the expansion of a gas. How much work is performed by the gas during the expansion?



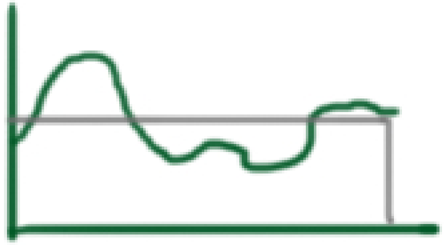
a. 900 J

b. 1150 J

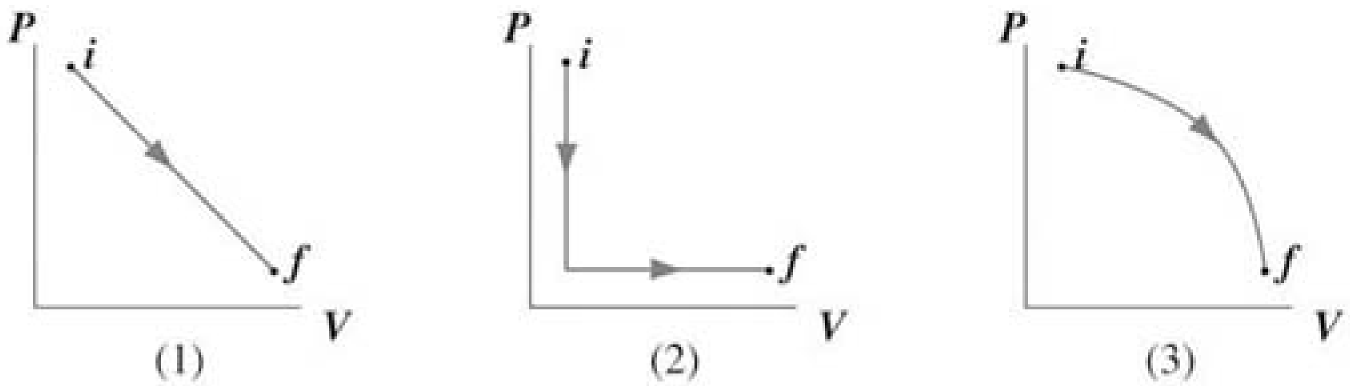
c. 90,000 J

d. 9×10^5 J

$(3\times10^5\,Pa)(3\times10^{-3}\,m^3)$



An ideal gas is taken from the same initial state and same final state by the three alternative pathways:



Which of the following are equal for all three pathways.

$\Delta U = Q - W$

same   different   different

I. work done by the gas

II. heat flow between the gas and the surroundings

III. internal energy change $U = \frac{3}{2} n R T$

IV. temperature change

state functions

a. II only

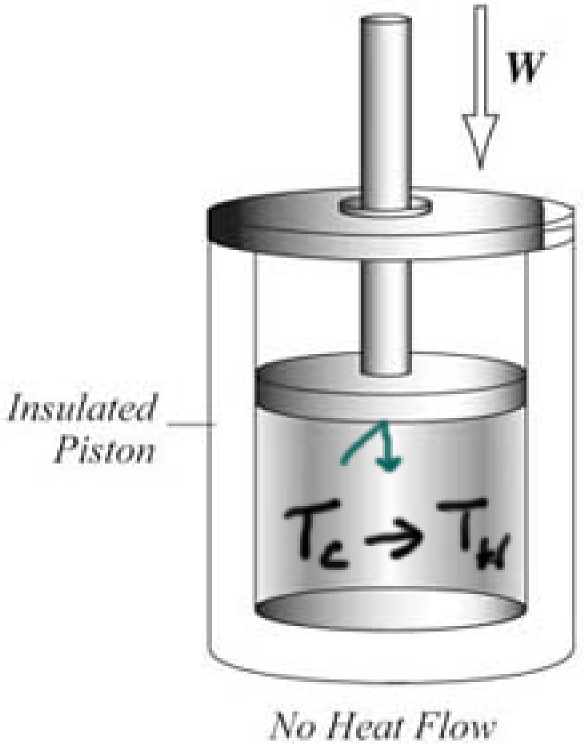
b. II and IV

c. III and IV

d. I, II, III, and IV

Adiabatic Process

↖ no heat flow



$$Q = 0$$

$$\Delta U = -W$$

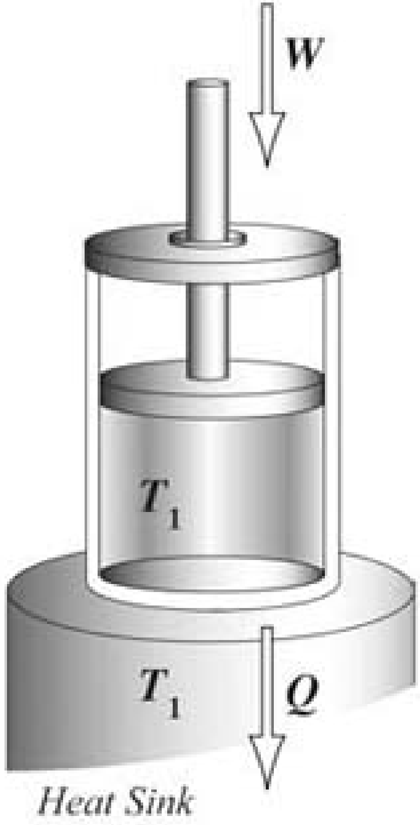
First law of thermodynamics for an adiabatic process

Q	=	heat flow
ΔU	=	internal energy change
W	=	macroscopic work

In an adiabatic process, no heat flow occurs, so internal energy change directly corresponds to the work performed.

Isothermal Process

↖ constant T

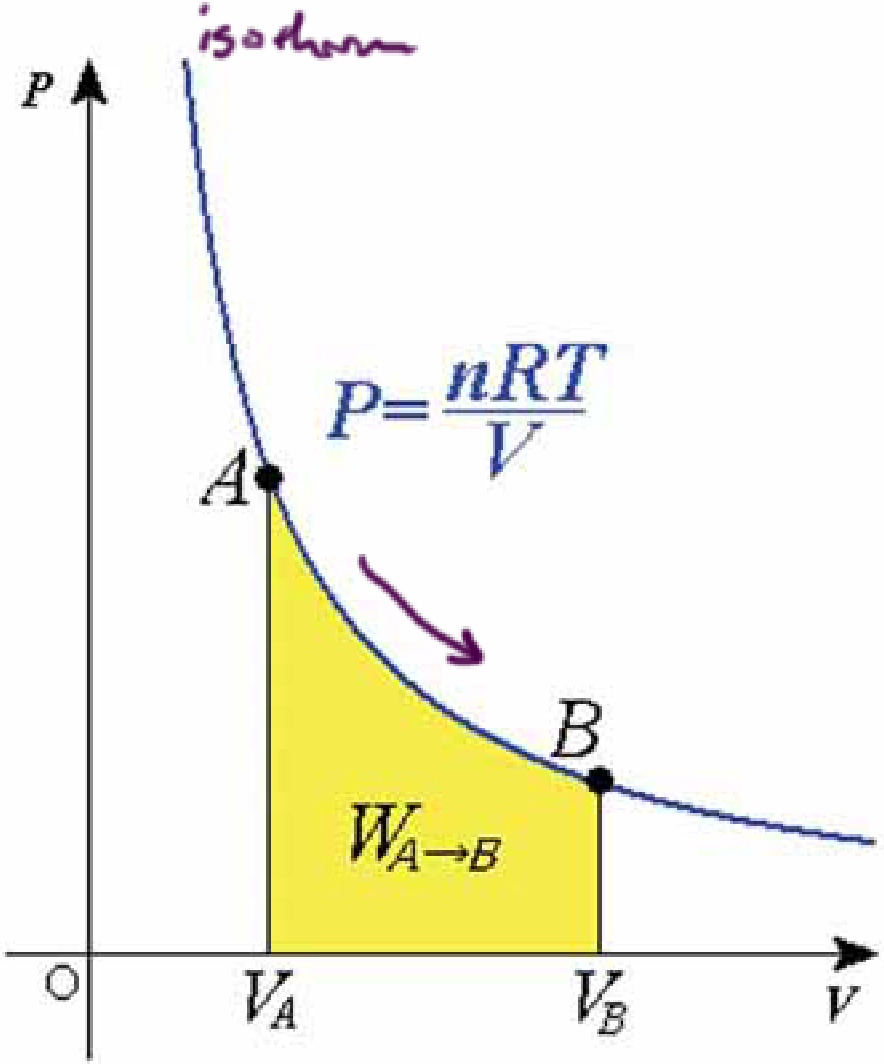


$$\Delta U = 0$$
$$Q = W$$

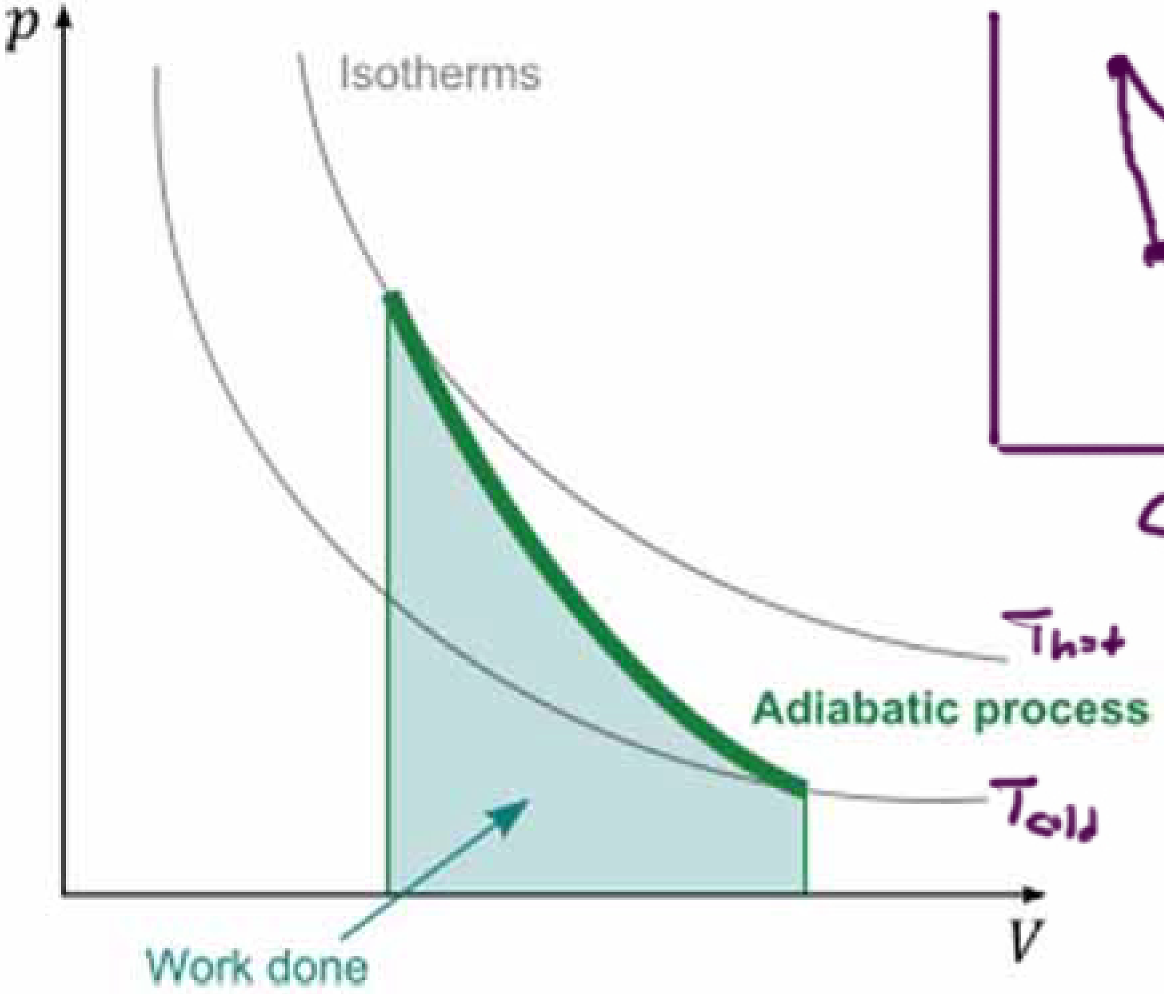
First law of thermodynamics for an isothermal process

ΔU = internal energy change
Q = heat flow
W = macroscopic work

In an isothermal process on an ideal gas, the temperature is constant. Because temperature is constant, internal energy must be constant. If internal energy is constant, any work that occurs must be balanced by heat flow.



isotherm
P
P = nRT/V
A
B
W_{A→B}
O
V_A
V_B
V

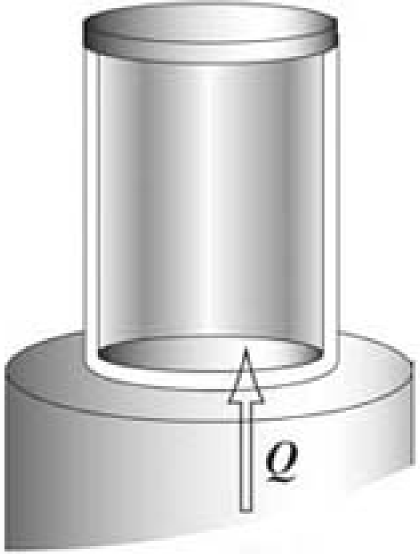


Carnot cycle

Isovolumetric Process

isochore

Work $P\Delta V$
$\Delta V = 0$
no work



Heat Sink

$$W = 0$$

$$\Delta U = Q$$

First law of thermodynamics for an isovolumetric process

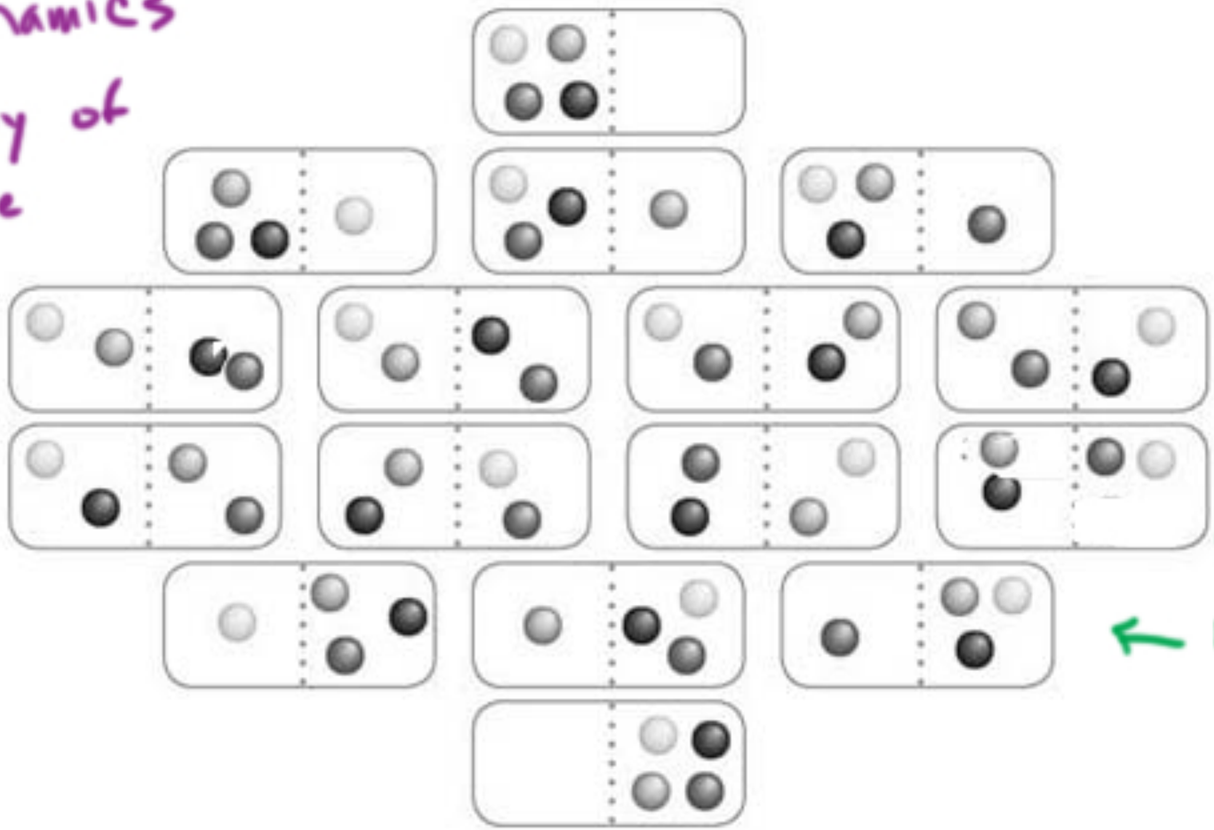
W	=	macroscopic work
ΔU	=	internal energy change
Q	=	heat flow

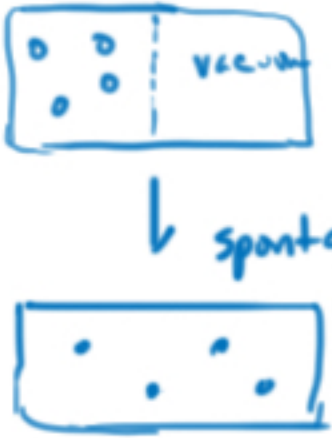
In an isovolumetric process, no thermodynamic work occurs. The only way internal energy changes is through heat flow.

Entropy

2nd Law of Thermodynamics

The entropy of the universe always increases.





↓ spontaneous (not reversible)

↑ statistical ensemble of microstates

← microstates

$S = k \ln X$

↑ multiplicity

An isolated system tends toward disorder (greater entropy) because disordered states are more probable. Possible disordered states outnumber ordered states.

- In the system below, two bulbs are connected by a tube and stopcock. In the initial state, all of the gas (*N* particles) is constrained to occupy a single bulb. When the stopcock is opened, the gas spontaneously moves to occupy both bulbs. In this example, with the stopcock opened, the probability of the second state is 2^N times that of the initial state.

- Entropy rises with the multiplicity of the system (the number of possible internal configurations that correspond to a particular macrostate).

$$S = k \ln X$$

S = entropy
k = Boltzmann's constant
X = multiplicity

Free expansion is an irreversible process in which a gas expands into an insulated evacuated chamber. During a free expansion

I. the temperature remains constant
II. the entropy of the gas increases
III. the internal energy of the gas remains constant

A. I
B. I and III
C. II and III
D. I, II, and III

Carbon monoxide is a linear molecule. The carbon and oxygen atoms are roughly the same size and the dipole moment of the molecule is relatively small. This means that at temperatures just below its freezing point (74K), the molecules of this substance can flip easily in the crystal and assume one of two orientations with equal probability. The probability of flipping vanishes at even lower temperatures, though, as the temperature approaches absolute zero, where motion ceases and only one quantum energy state is available to each molecule. At absolute zero, the theoretical entropy of pure carbon monoxide crystal would be:

a. zero

b. a small positive value

c. a small negative value

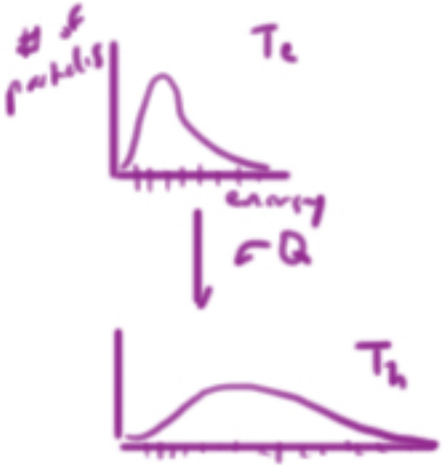
d. absolute zero is impossible to attain

carbon monoxide

Entropy Change Due to Heat Flow

$$\Delta S = \frac{\Delta Q_r}{T}$$

ΔS = entropy change
Q_r = heat flow (in reversible process)
T = temperature



entropy lost: $\Delta S_H = \frac{Q}{T_H}$ — T_H $\xrightarrow{Q}$ (spontaneous) T_c — entropy gained: $\Delta S_c = \frac{Q}{T_c}$

↓

$T_w \rightleftharpoons T_w$

thermal equilibrium

- entropy gained by the cold body is greater than what was lost by the hot body.
- entropy of the universe increased.

$\Delta S_{universe}$ ⊕

When a hot stone is dropped into a cool water bath and heat flows from the stone into the bath

A. More entropy is lost in the stone than gained by the water.

B. More entropy is gained by the stone than lost by the water.

C. Less entropy is lost by the stone than gained by the water.

D. The change in entropy in the stone is balanced by an equal and opposite change in entropy in the water.

$\Delta U = Q - W$

Which of the following does NOT change for a sample of ideal gas undergoing an adiabatic compression?

(A.) entropy (circled)
~~B.~~ internal energy
~~C.~~ pressure
~~D.~~ volume

$Q = 0$

$\Delta U = -W$

isentropic

$\Delta S_{universe} = 0$

reversible

Which of the following does NOT change for a sample of ideal gas undergoing an isothermal compression?

~~A.~~ entropy
(B.) internal energy (circled)
C. pressure
D. volume

ΔS_{system} loss Q/T_0

$\Delta S_{surroundings}$ gain Q/T_0

$\Delta S_{universe} = 0$

$\Delta U = 0$

$Q = W$

also reversible

A sealed container holds 1-L of hydrogen gas (H_2) at STP. A second sealed container holds 1-L of helium gas (He) at STP. Both containers are heated isochorically to 100°C. Which gas experiences the greatest change in entropy?

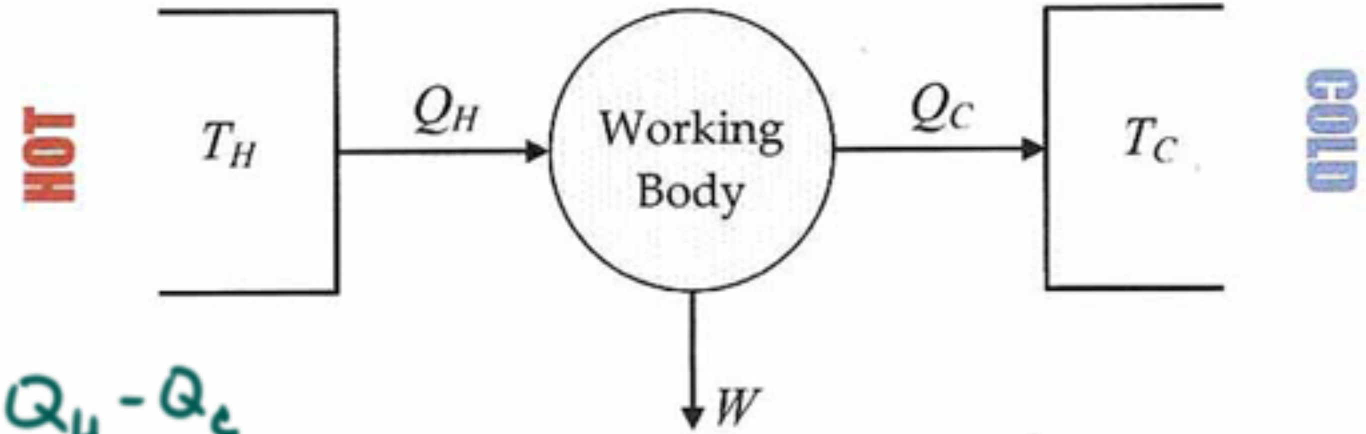
• same # of moles

$\Delta V = 0$

A. the hydrogen gas
B. the helium gas
C. both have equal changes in entropy
D. the entropy of neither gas changes

- How much of Q_H can we turn into work? thermal efficiency $\frac{W}{Q_H}$
- We know that we can turn none into work. That's spontaneous.
- Can we turn all of it into work? $\Delta S_H = \frac{Q_H}{T_H}$ ← hot body lost entropy

$\Delta S_{universe}$ would be ⊖ ← impossible



$W = Q_H - Q_c$

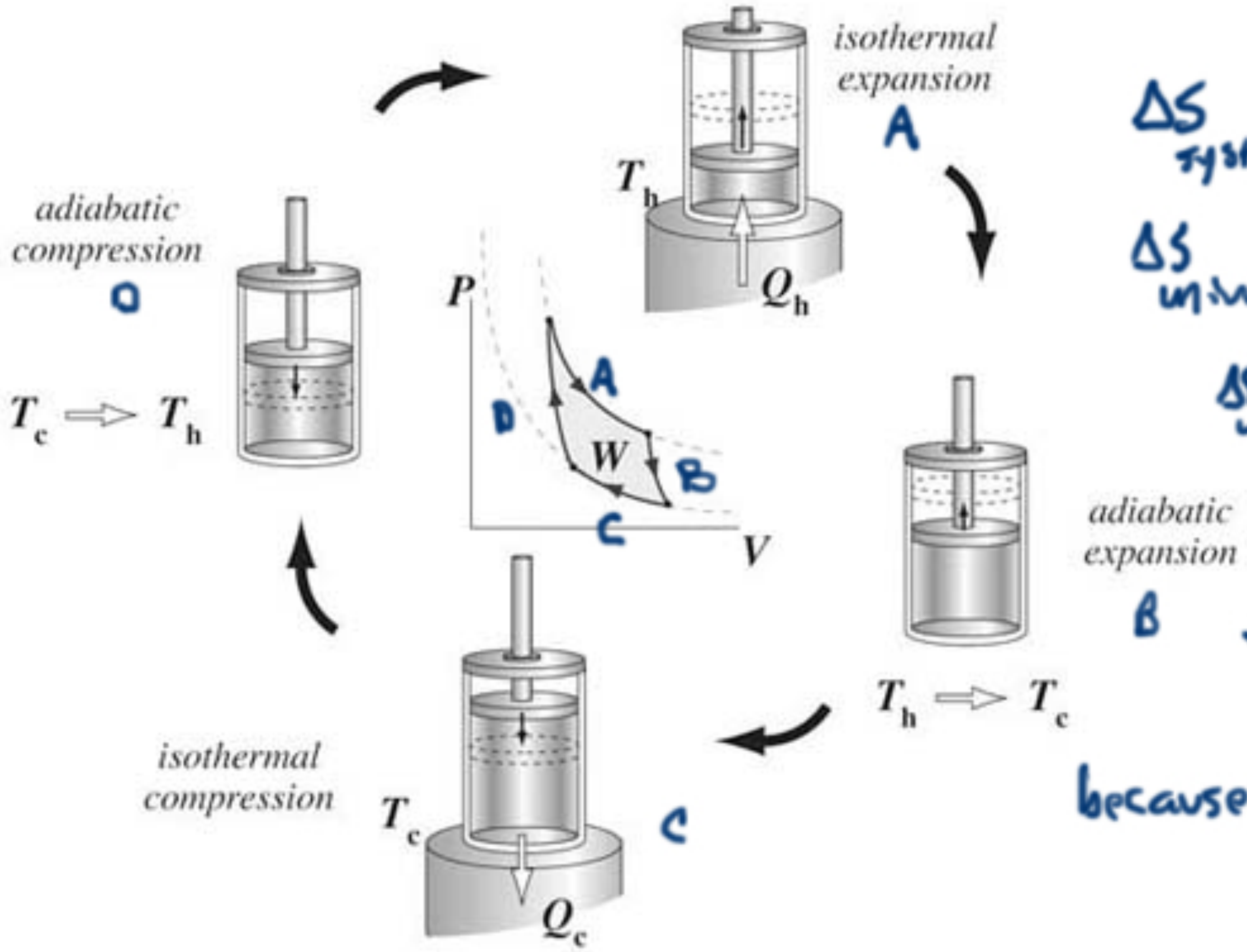
Best we can do is a reversible engine. $\frac{Q_H}{T_H} = \frac{Q_c}{T_c}$

combine equations: $\varepsilon = \frac{W}{Q_H} = 1 - \frac{T_c}{T_H}$

entropy lost = entropy gained

$\Delta S_{universe} = 0$

The Carnot Cycle



A Reversible Engine

$\Delta S_{system} = 0$ It's a cycle!

$\Delta S_{universe} = 0$ all stages are reversible

$$\Delta S_{universe} = \Delta S_{system} + \Delta S_{surroundings}$$

$\Delta S_{surroundings} = 0$

therefore $\frac{Q_H}{T_H} = \frac{Q_c}{T_c}$

because $W = Q_H - Q_c$

$$\varepsilon = \frac{W}{Q_H}$$

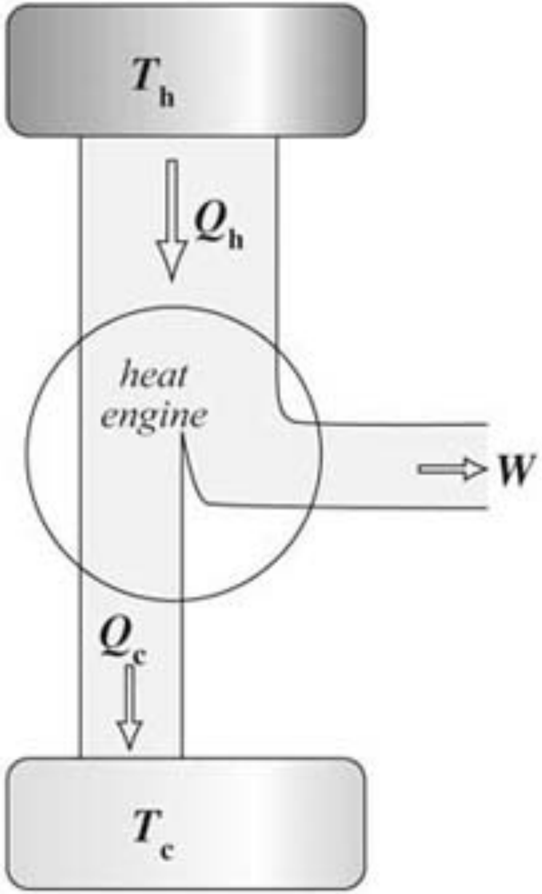
$$\varepsilon = 1 - T_c/T_H$$

The Thermal Efficiency of a Heat Engine

$$\varepsilon = \frac{W}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h}$$

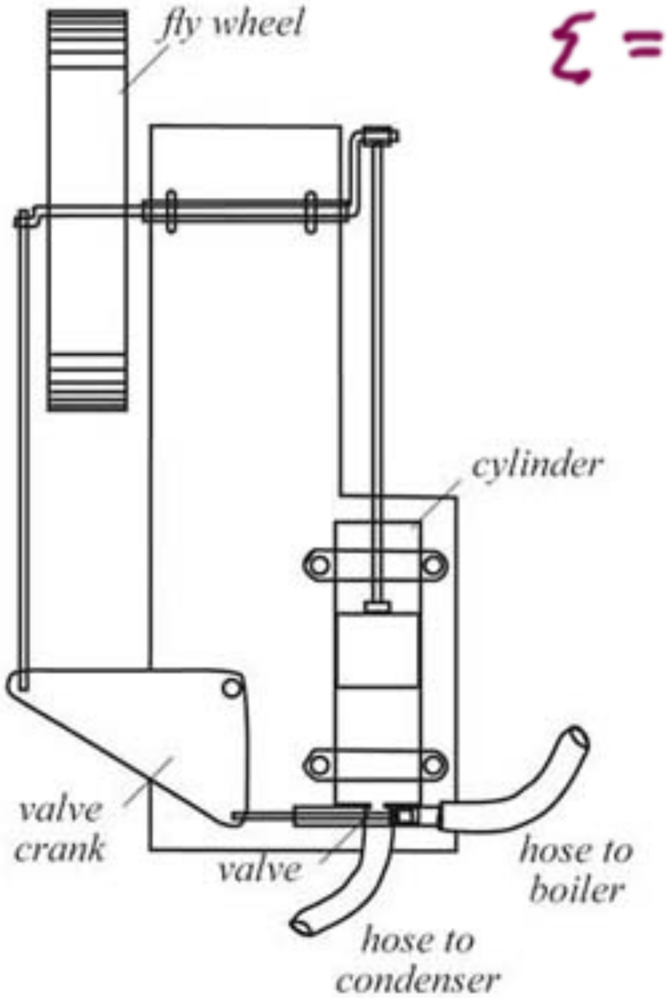
$$\varepsilon = \frac{T_h - T_c}{T_h} = 1 - \frac{T_c}{T_h}$$

(with heat input and output occuring at fixed temperatures)



ε = thermal efficiency
W = net work
Q_h = heat flow in
Q_c = heat flow out
T_h = hot sink temperature
T_c = cold sink temperature

Which of the following would tend to increase the thermal efficiency of the single stroke steam engine at right?



$\varepsilon = 1 - \frac{T_2}{T_{1+}}$

I. Increasing boiler temperature

II. Decreasing boiler temperature

III. Increasing condenser temperature

IV. Decreasing condenser temperature

a. I only

b. I and IV

c. II only

d. II and III

What is the maximum efficiency of an engine operating between 177 °C and 27 °C?

A. 33%
B. 85%
C. 50%
D. 15%

convert to Kelvin!

$$\varepsilon = 1 - \frac{T_c}{T_H}$$

$$= 1 - \frac{300\,K}{450\,K}$$

$$= 33\%$$

Coefficient of Performance

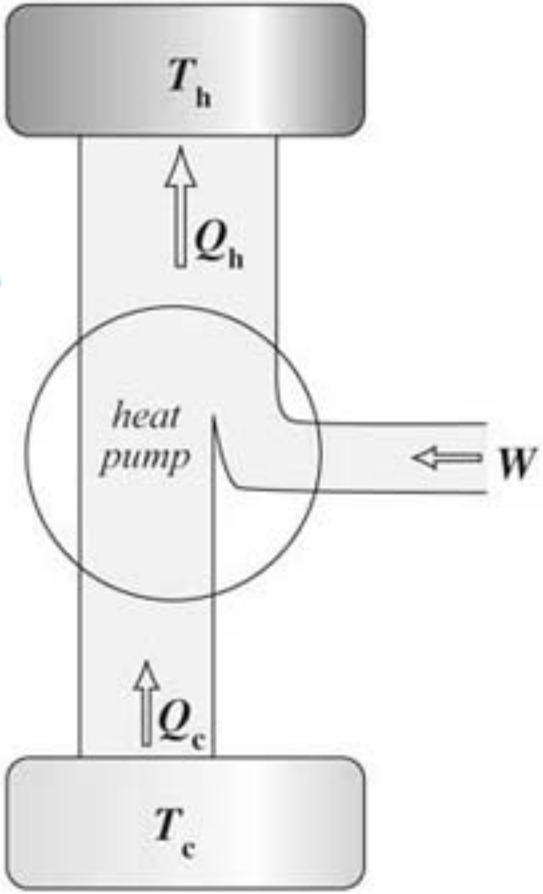
$$\mathrm{COP} = \frac{Q_h}{W}$$

$$= \frac{T_h}{T_h - T_c}$$

$\frac{300\,K}{300\,K - 270\,K}$

$= 10$

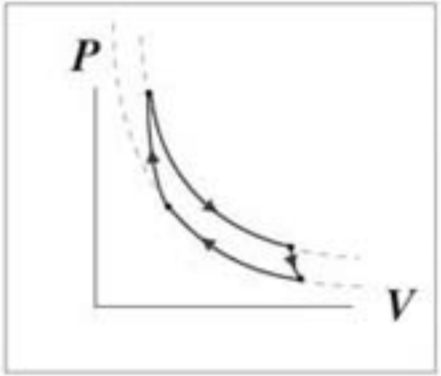
(with heat input and output occuring at fixed temperatures)

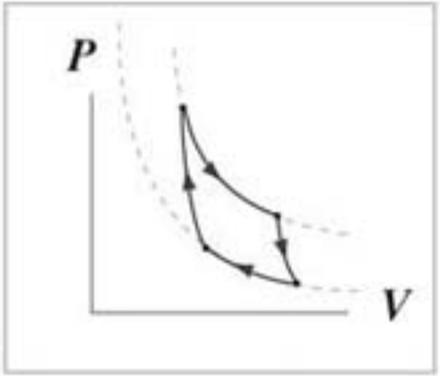


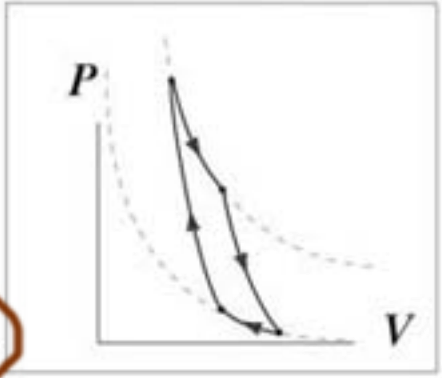
ε	=	thermal efficiency
W	=	net work
Q_h	=	heat flow in
Q_c	=	heat flow out
T_h	=	hot sink temperature
T_c	=	cold sink temperature

Which of the pressure-volume graphs below depicts the most efficient Carnot cycle?

$$\varepsilon = 1 - \frac{T_c}{T_H}$$

a. 

c. 

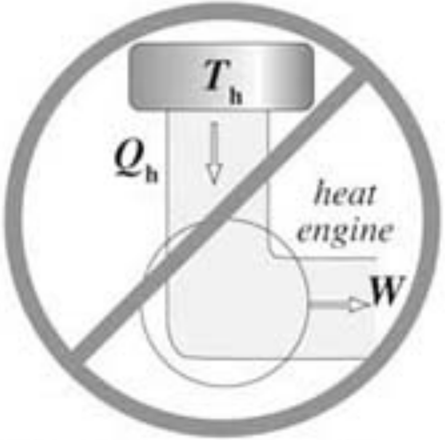
b. 

d. All three are equally efficient.

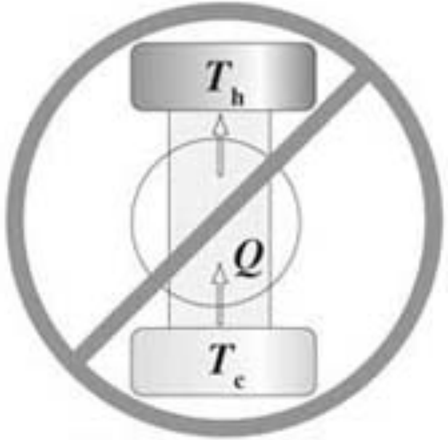
The Second Law of Thermodynamics

The entropy of the universe increases for all real processes.

No heat engine operating on a cycle can be 100% efficient (Kelvin's formulation).



Kelvin's formulation of the second law of thermodynamics

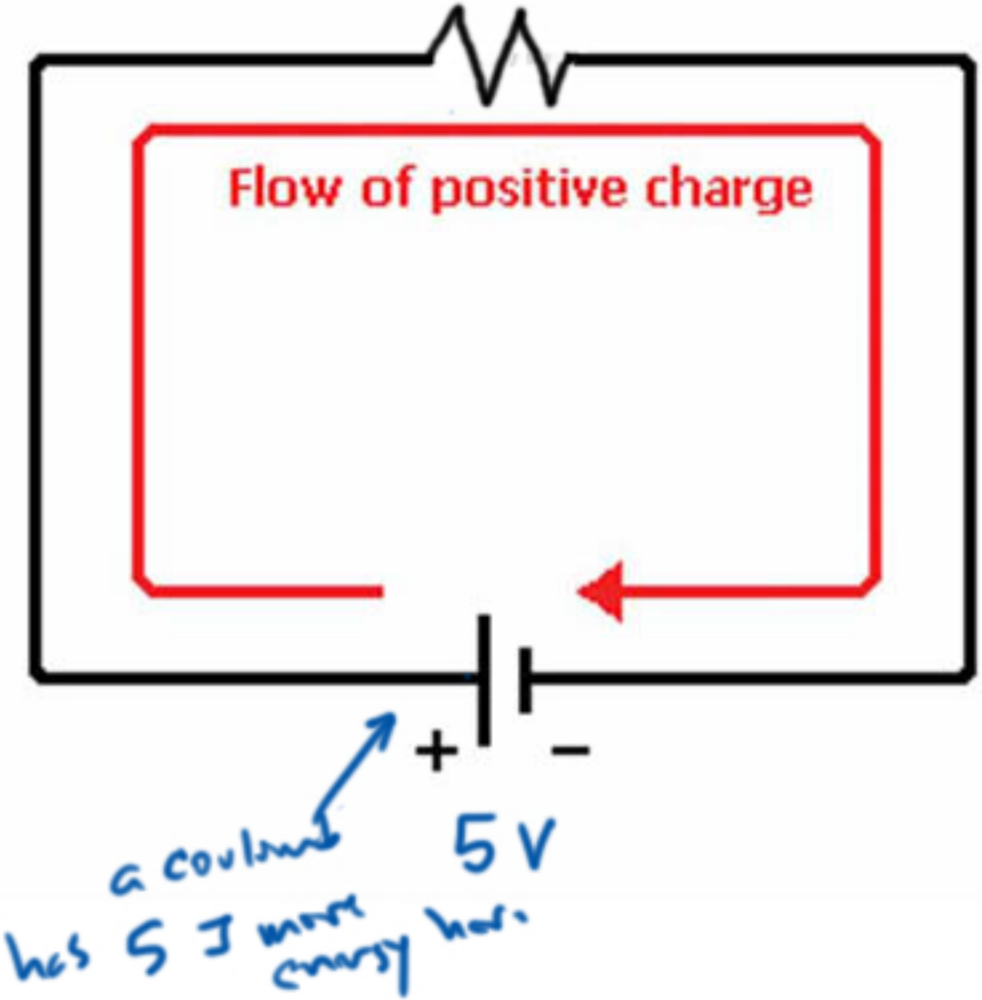


Clausius' formulation

An engine cannot transfer heat continuously from a colder to a hotter body and produce no other effects (Clausius' formulation).

DC Current

- current (I)
  - ampere
  - $1\,A = C/s$
- voltage (V)
  - $1\,V = J/C$
- resistance (Ω)

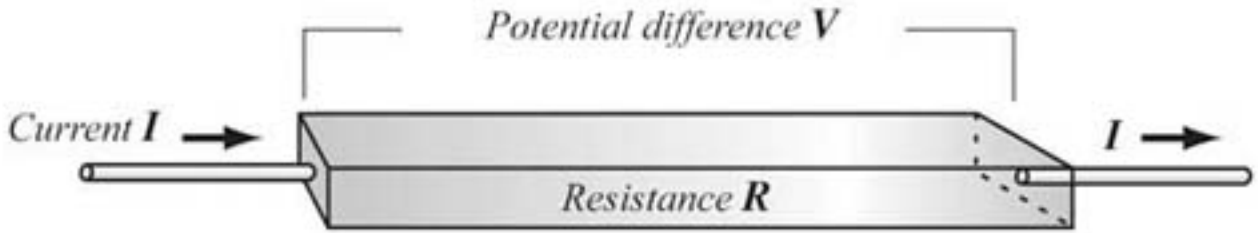


Ohm's Law

$$V = IR$$

$$I = \frac{V}{R}$$

V = electric potential
I = current
R = resistance



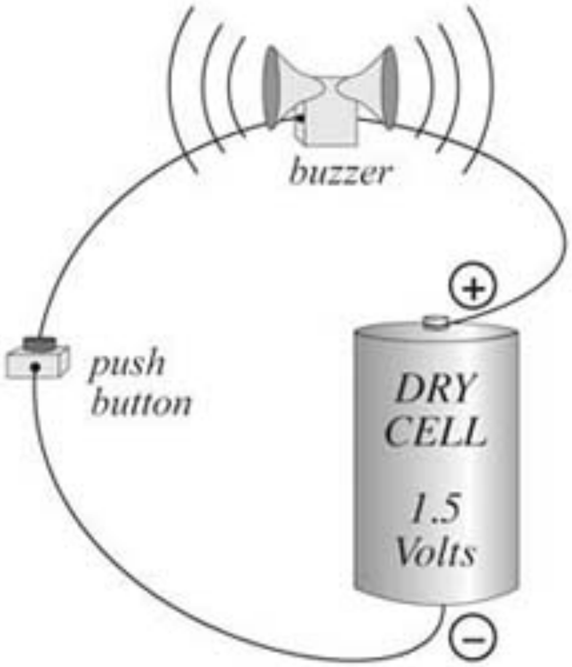
When the push button at right is depressed, the 1.5 V battery causes the 50 Ω buzzer to sound. What current flows through the circuit?

a. 15 mA

b. 30 mA

c. 75 A

d. 150 A



$V = IR$

$I = V/R$

$= \frac{1.5\ V}{50\ \Omega}$

Resistance of a Uniform Conductor

$$\rho = \frac{1}{\sigma}$$

↑ conductivity especially important for solutions of electrolyte

$$R = \frac{L}{\sigma A} = \rho \frac{L}{A}$$

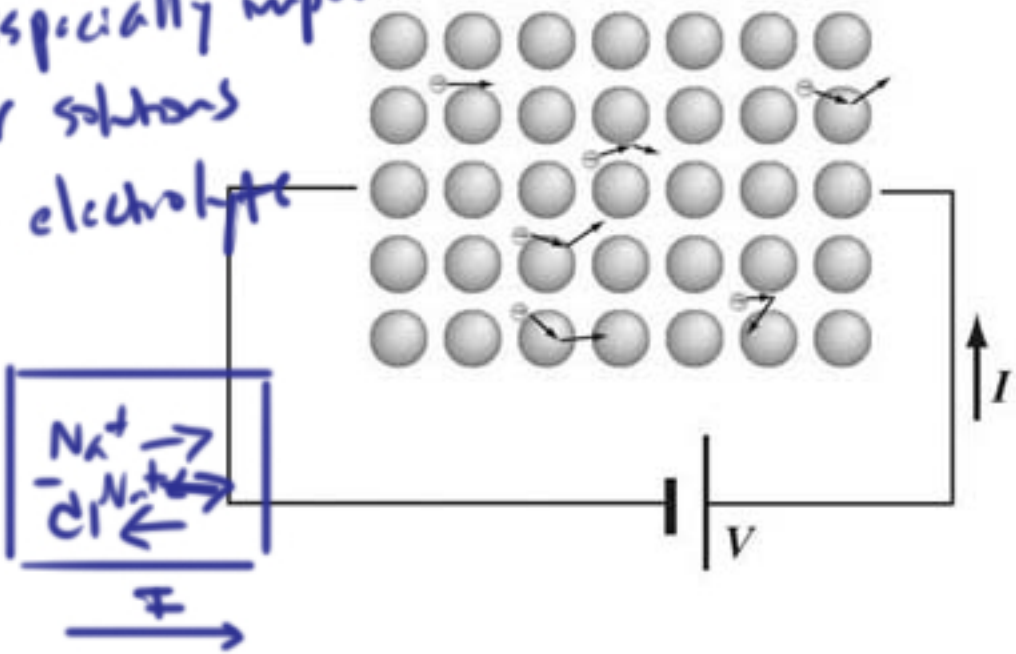
R	=	resistance
L	=	resistor length
A	=	resistor cross-sectional area
σ	=	conductivity
ρ	=	resistivity ($1/\sigma$)

Metal conductors

- Resistance increases with T

Semiconductors

- Resistance decreases with T

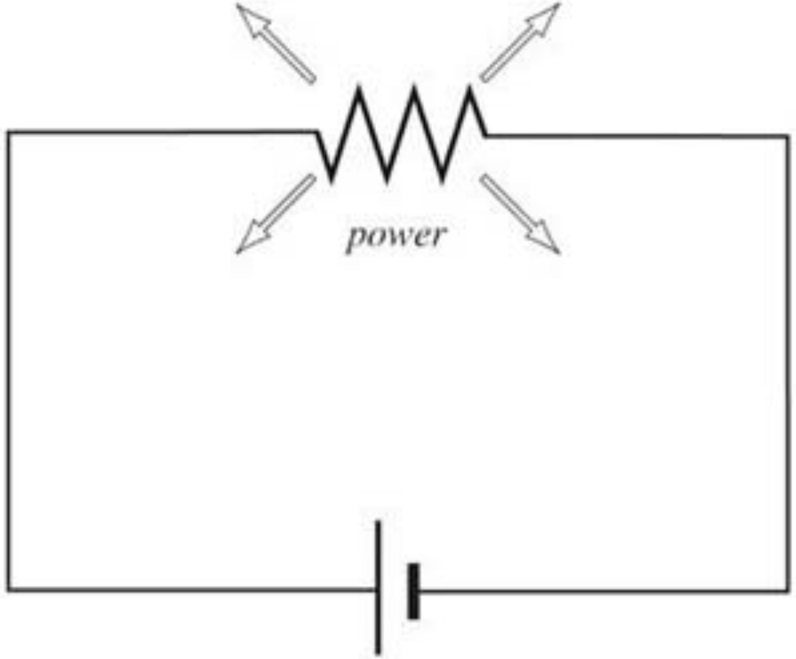


By convention, the direction of current is expressed as the flow of positive charge, which is opposite the direction of electron flow in a metallic conductor.

Electric Power

$$P = IV = I^2R = \frac{V^2}{R}$$

P = power
I = current
V = potential
R = resistance

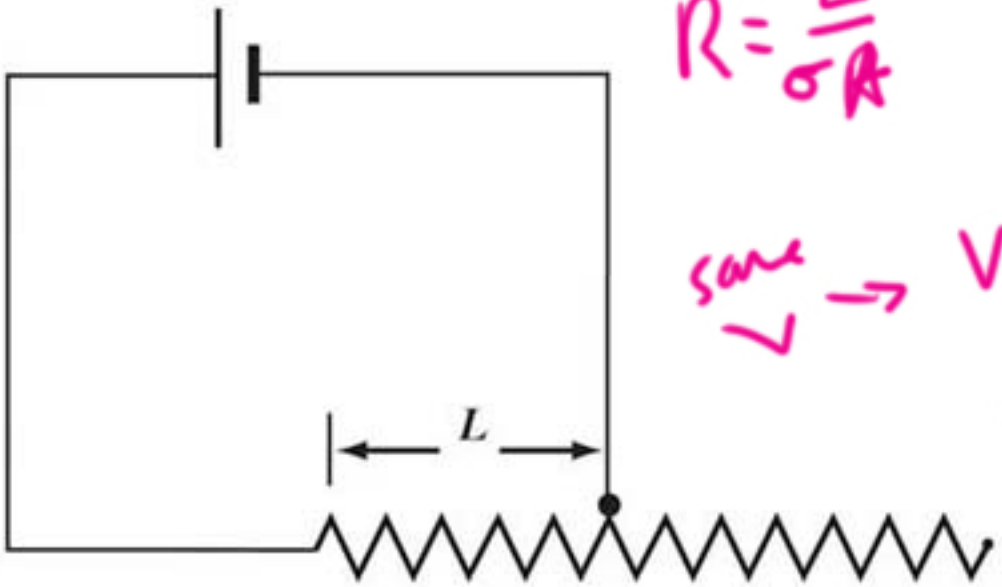


$$P = IV$$

$$\left(J/s\right) = \left(C/s\right)\left(J/C\right)$$

$$1\ J/s = 1\ \text{watt}$$

With neglible internal resistance, a battery delivers a steady voltage to a variable resistor. With P_i representing the initial power output, what is the final power of the circuit when the length of the variable resistor is halved?



$R = \frac{L}{\sigma A}$ $\frac{1}{2}L \Rightarrow \frac{1}{2}R$

same V → $V = IR$

twice the current

a. $\frac{P_i}{4}$ b. $\frac{P_i}{\sqrt{2}}$ c. $2P_i$ d. $4P_i$

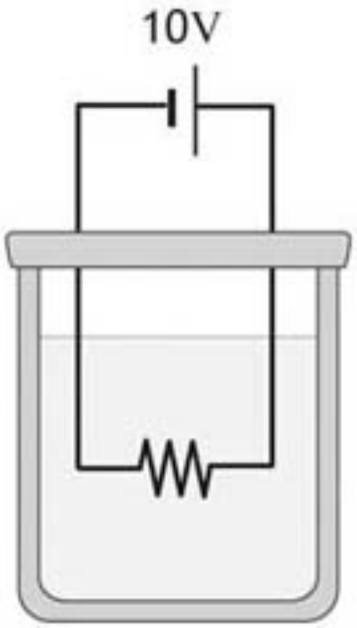
A 10V battery delivers current to a resistor immersed in 100g water within a Dewar flask. What is the approximate current if the temperature of the water rises by one degree celsius (1°C) per second?

$c = 1\ cal/g \cdot °C$

$P = 100\ cal/s$

$1\ cal = 4.18\ J$

$= 400\ J/s$



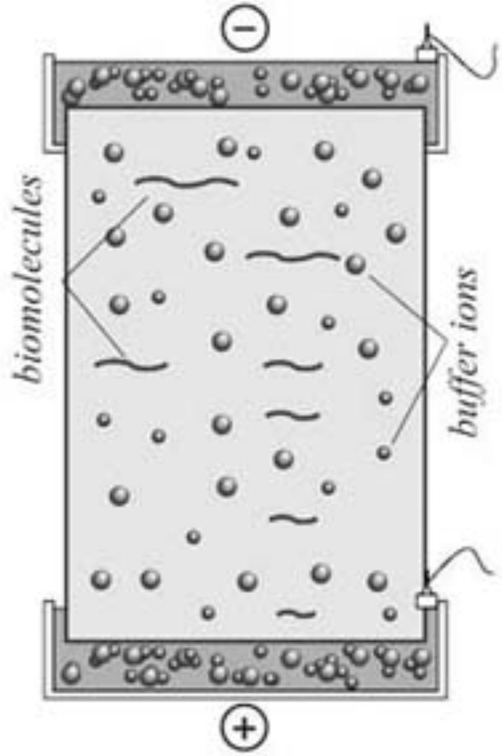
a. 1 A

b. 2.5 A

c. 10 A

d. 40A

The varying mobility of biomolecules impelled by an electric field to migrate through a gel matrix enables their separation in gel electrophoresis. A buffered electrolyte solution provides the majority of electrical conductivity to the matrix. If a researcher inadvertently used a buffer solution of half normal concentration with the power supply set to its normal rate of constant current, which of the following would occur? *(Biomolecule charge-to-mass ratio unaffected).*



a. Slower migration of biomolecules

b. Increased apparatus temperature

c. Unchanged electrical parameters

d. Decreased electric field strength

$V = Ed$

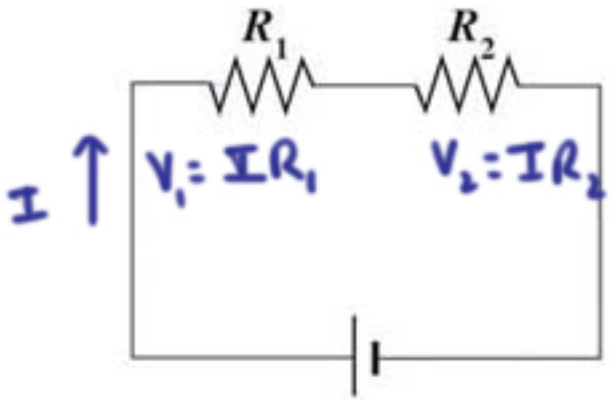
Resistance has increased!

Current stayed same.

Voltage increases.

Power increased

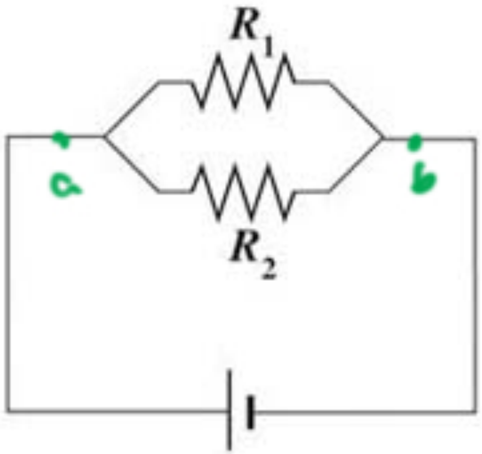
Equivalent Resistance of Series or Parallel Resistors



- current is the same through series resistors
- voltage drops as you go

$$R_{\text{ser}} = R_1 + R_2 + R_3 + \cdots$$

The equivalent resistance of resistors in series is greater than the resistance of any individual resistor in the series.



- voltage is the same across parallel resistors
- current follows the path of least resistance.

$$\frac{1}{R_{\text{par}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

The equivalent resistance of resistors in parallel is less than the resistance of any individual resistor in parallel.

$$\frac{1}{R_{par}} = \frac{1}{R_1} + \frac{1}{R_2}$$

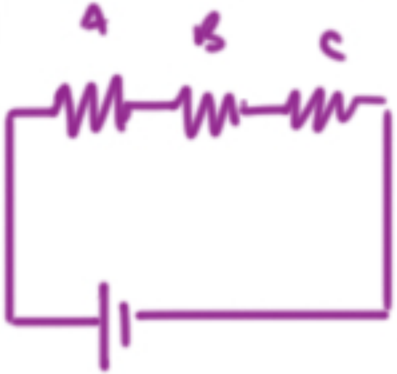
$$R_{par} = \frac{R_1 R_2}{R_1 + R_2}$$

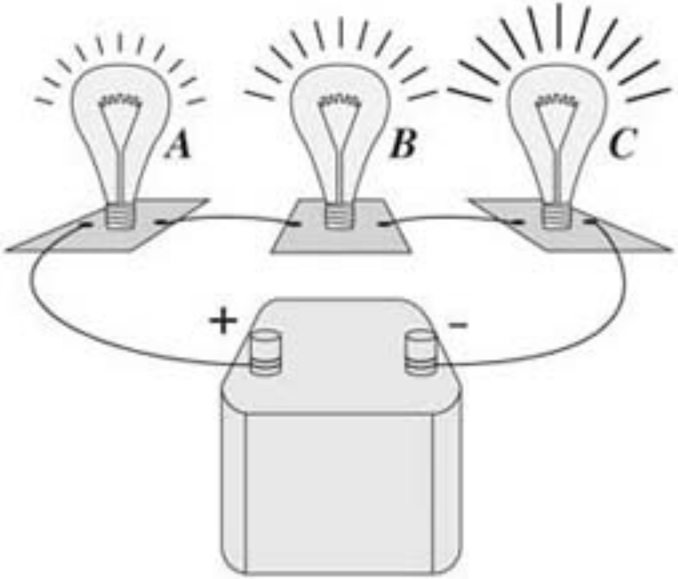
When three light bulbs of different wattage are attached in series to a steady DC power source, the order of brightness is $C > B > A$. If the circuit is then reconfigured so that the three bulbs are arranged in parallel, what would be the order of brightness in the new configuration?

$P_C > P_B > P_A$

$V_C > V_B > V_A$

$R_C > R_B > R_A$





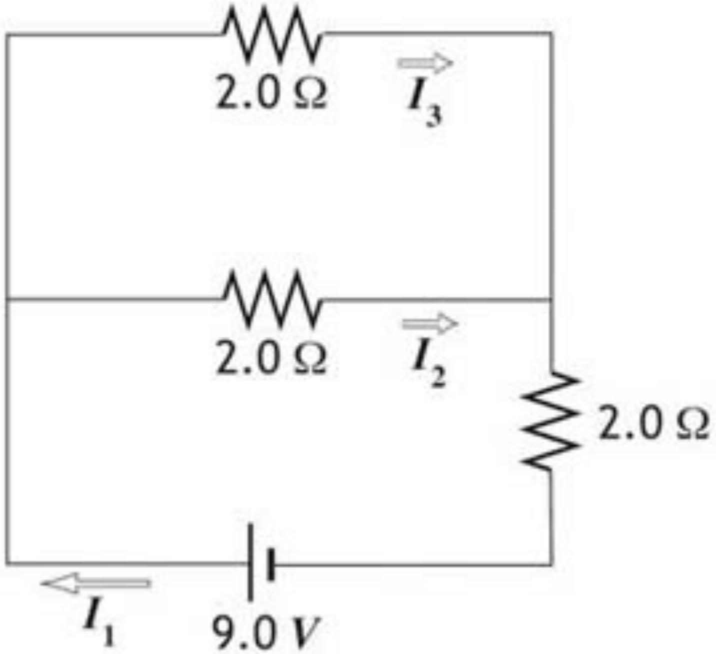
a. $A > B > C$

b. $B > A > C$

c. $C > B > A$

d. $A = B = C$

What is the value of the primary current, I_1?



$R_{pw} = 1\,\Omega$

a. 1.5 A

b. 2.25 A

c. 3.0 A

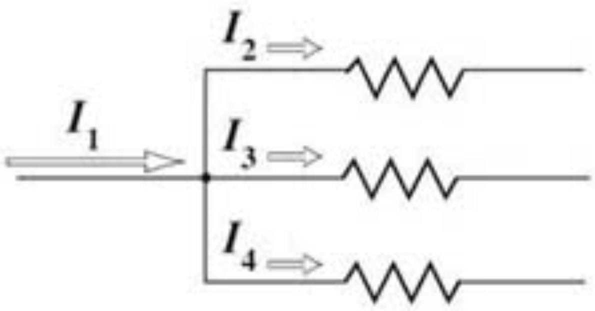
d. 4.5 A

Kirchhoff's Rules

Kirchhoff's First Rule (Branch Theorem)

$$I_1 = I_2 + I_3 + I_4$$

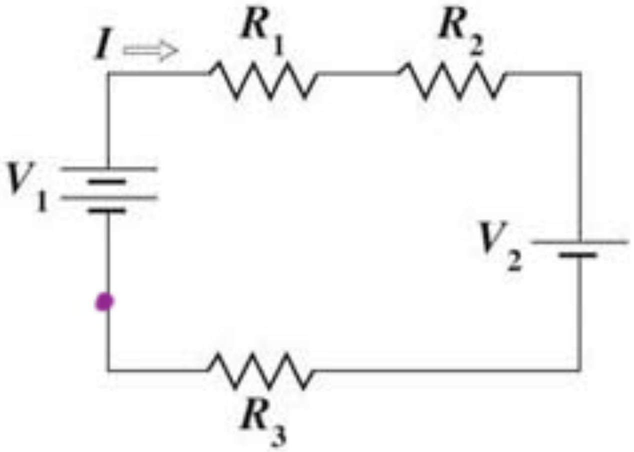
The sum of the currents into a junction equals the sum of currents out of the junction.



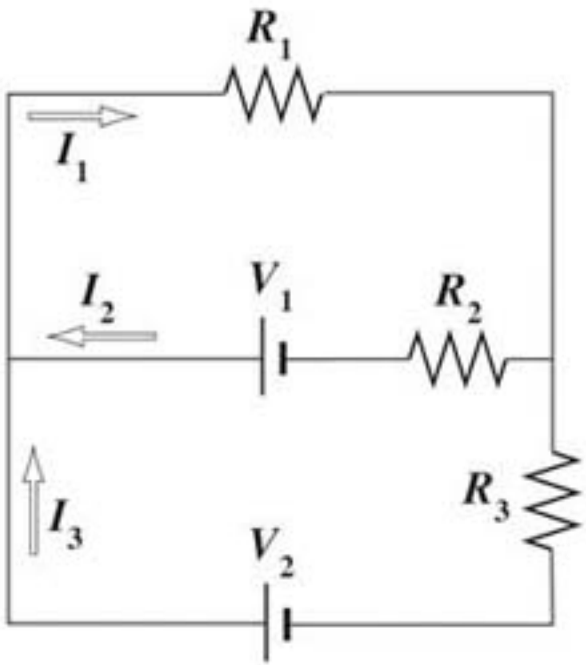
Kirchhoff's Second Rule (Loop Theorem)

$$V_1 - IR_1 - IR_2 - V_2 - IR_3 = 0$$

The sum of the changes in potential around any closed path is zero.



Which of the following statements validly describes the circuit at right?



I. $V_1 - I_1R_1 - I_2R_2 = 0$

II. $V_1 - V_2 + I_3R_3 - I_2R_2 = 0$

III. $I_1 = I_2 + I_3$

IV. $V_2 - I_1R_1 - I_3R_3 = 0$

a. I only

b. I and II

c. I, II and III

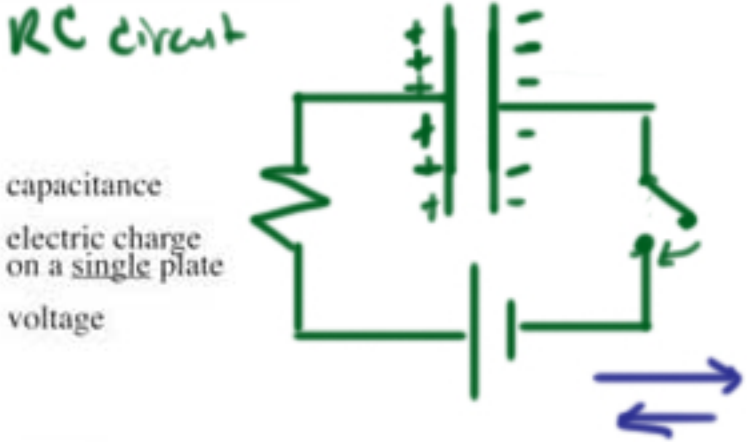
d. I, II, III, and IV

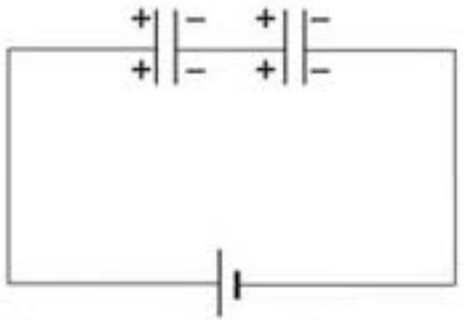
Capacitance

A capacitor with a high capacitance can hold a large amount of charge without requiring a high voltage.

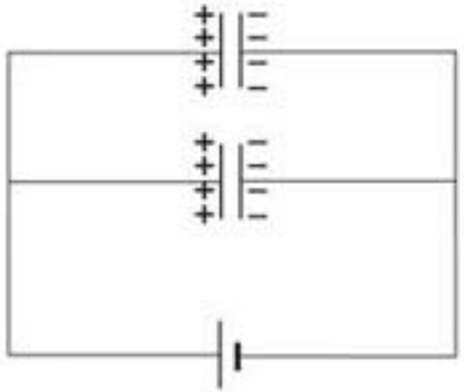
$$C = \frac{Q}{V}$$

C = capacitance
Q = electric charge on a single plate
V = voltage

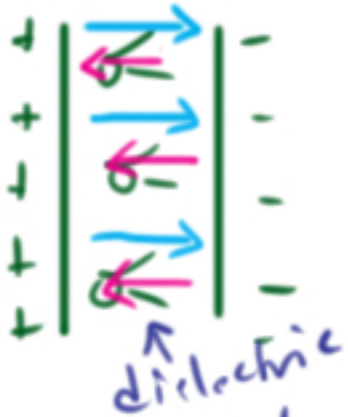




$$\frac{1}{C_{ser}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$$



$$C_{par} = C_1 + C_2 + C_3 + \cdots$$

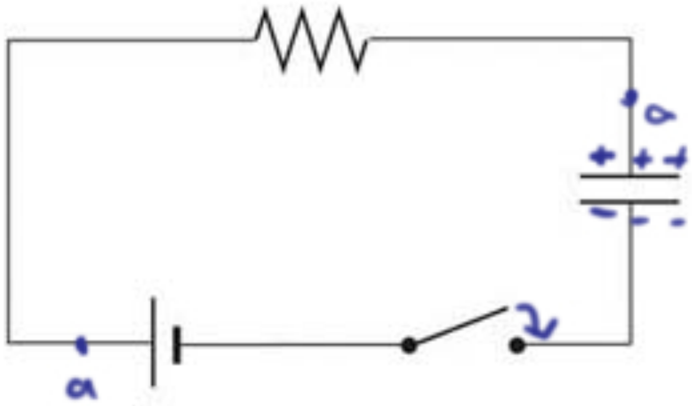


$V = Ed$

increased capacitance

Placing capacitors in series decreases the total capacitance, while placing capacitors in parallel increases the total capacitance.

The RC circuit at right consists of a capacitor in series with a battery, resistor and a switch. What occurs within the circuit after the switch is closed?



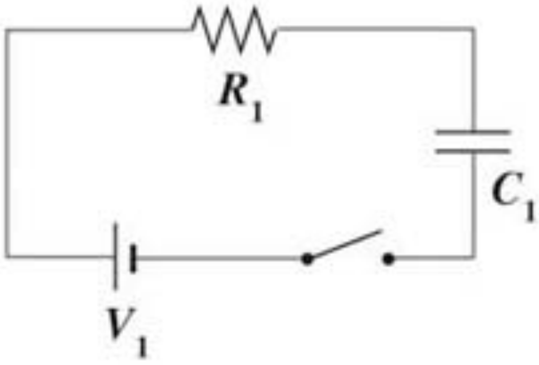
a. The voltage drop across the resistor decreases with time until there is no voltage acting across the resistor.

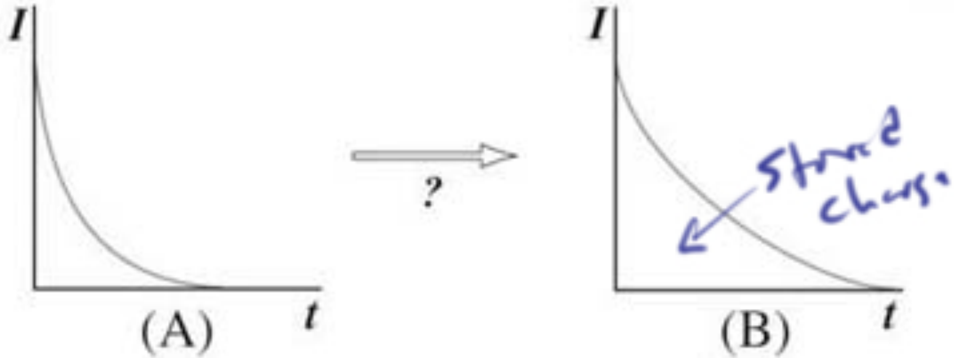
b. The current is not steady state. It slowly increases with time.

c. After the capacitor has fully charged, the current flows in the opposite direction.

d. The work done by the external voltage of the battery becomes stored potential energy in the charged capacitor.

Graph (A) shows the current vs. time that occurs after the switch is closed in the circuit at right. How could the circuit be altered to transform the current vs. time graph into graph (B)?





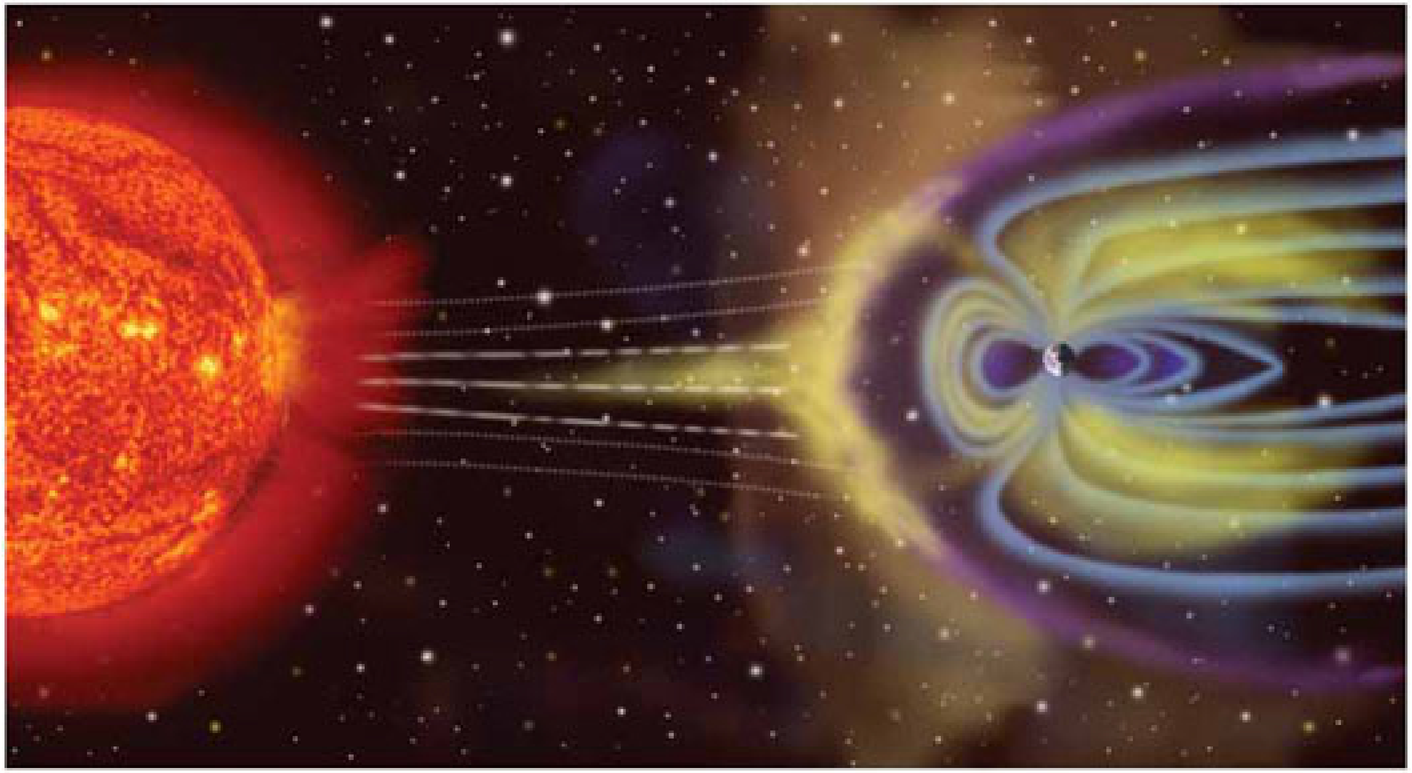
a. Include another resistor in series with R_1

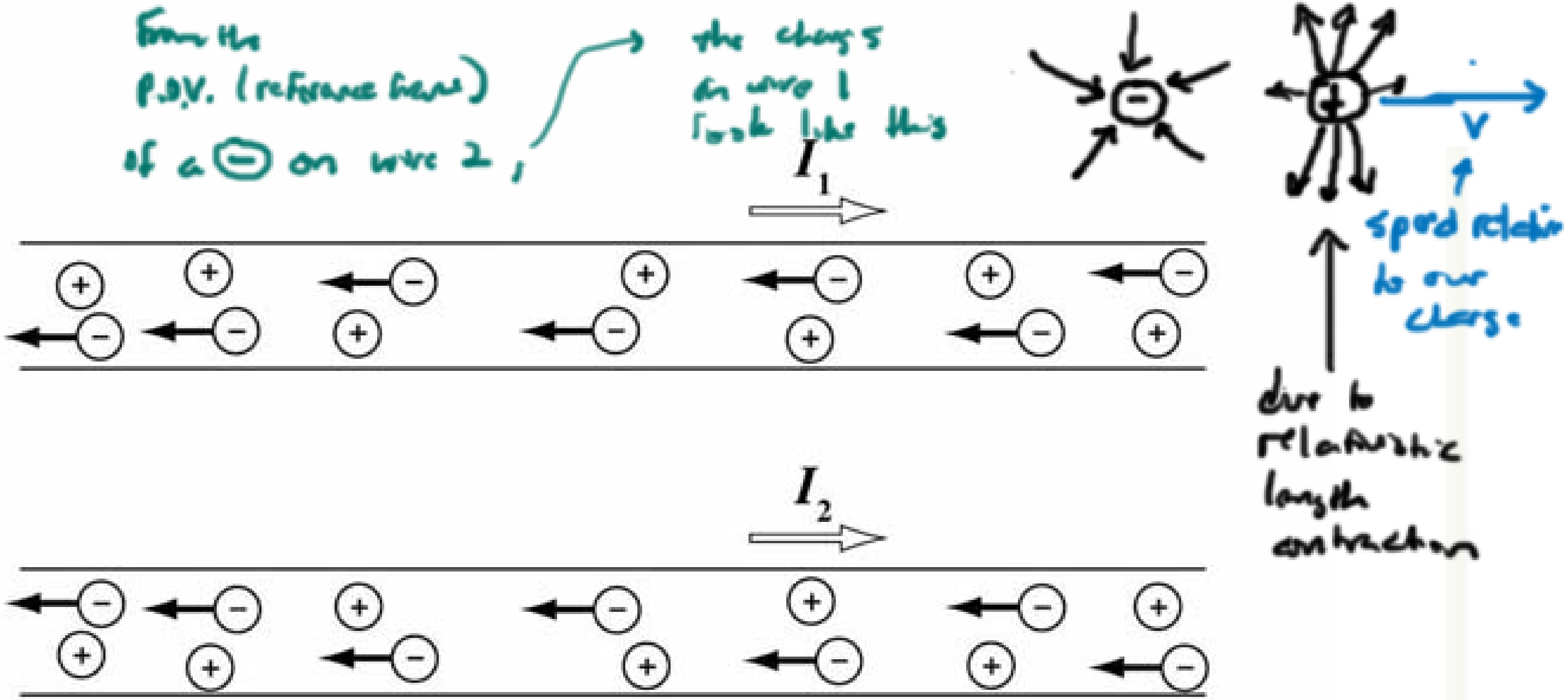
b. Include another resistor in parallel with R_1

c. Include another capacitor in series with C_1

d. Include another capacitor in parallel with C_1

Magnetism



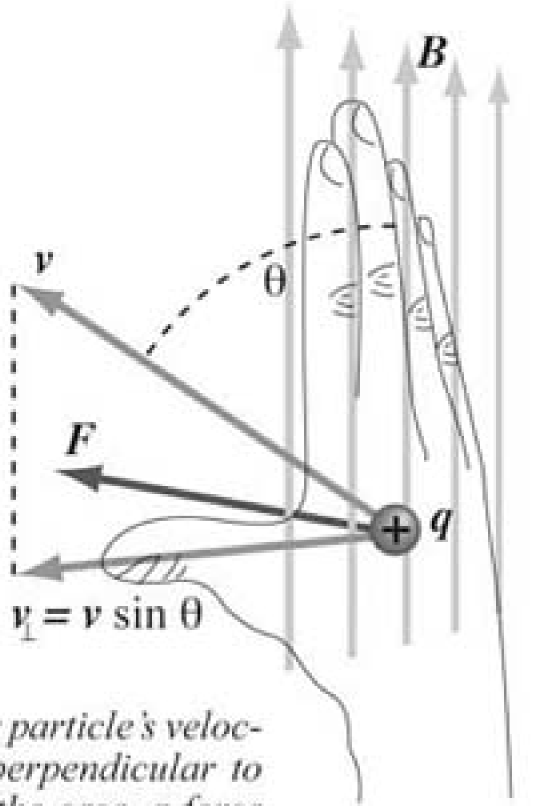


supplemental

Magnetic Force on a Moving Charge

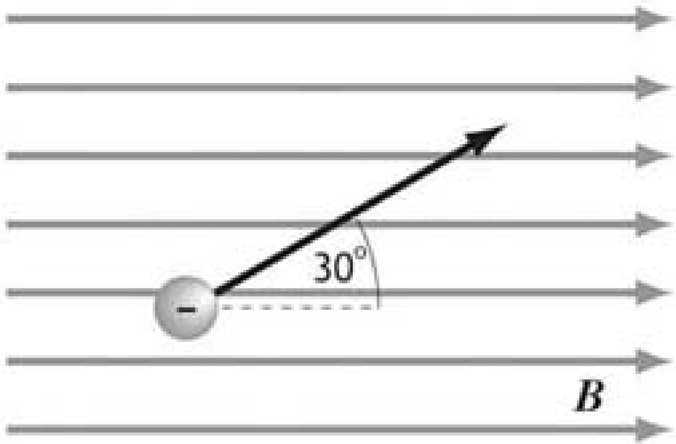
$$F = qB\, v \sin\theta$$

F	=	magnetic force
q	=	particle charge
B	=	magnetic field strength
v	=	particle speed
θ	=	angle between particle velocity and the magnetic field



To produce a magnetic force, a particle's velocity must have a component perpendicular to the magnetic field. If that is the case, a force is produced perpendicular to both the field and the particle's velocity.

A beta (β^-) particle (charge -1.6×10^{-19} C) moves at a speed of 1×10^5 m/s at an angle of 30° to a uniform 20T magnetic field in the plane of the image at right. What is the magnetic force on the particle?



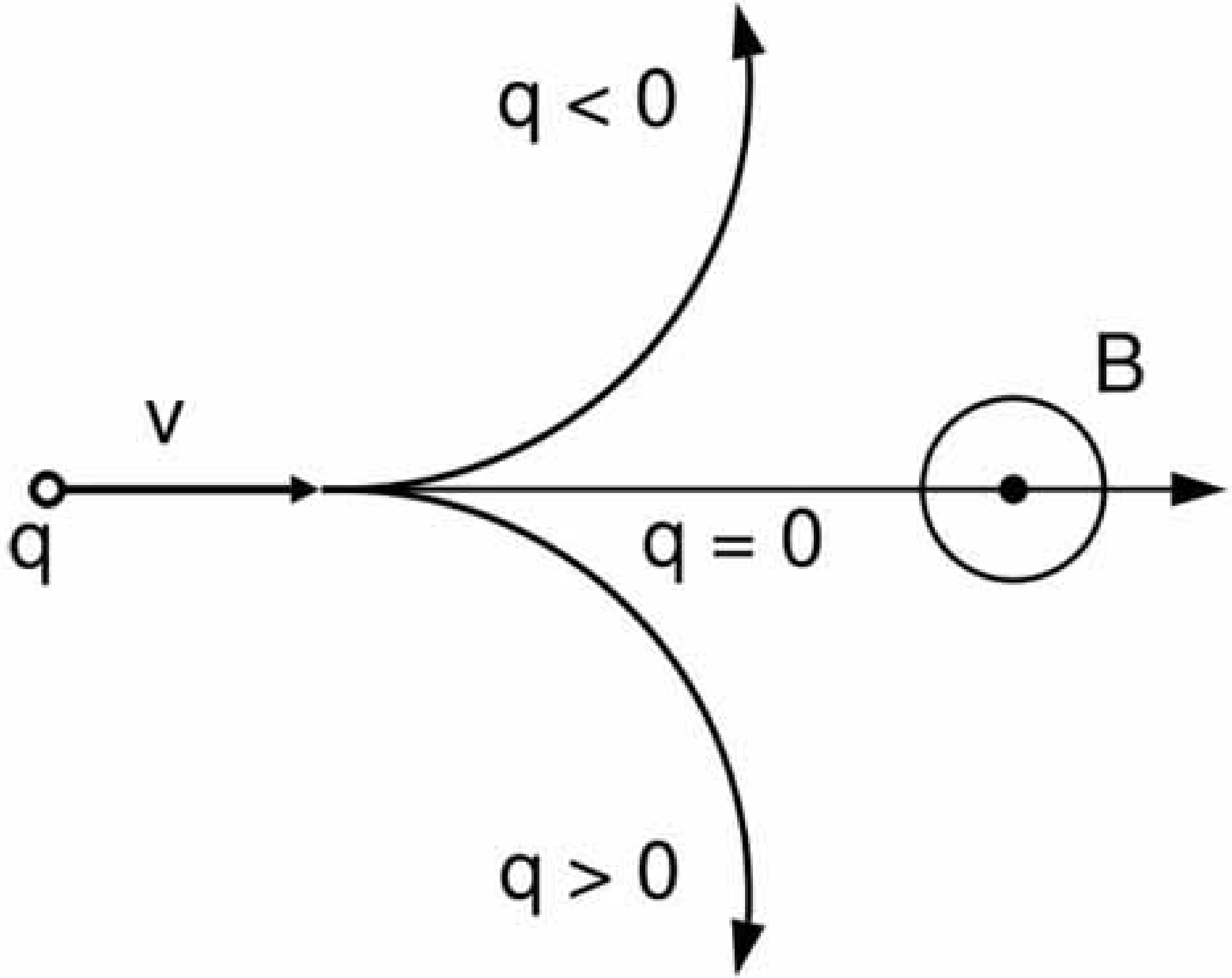
a. 1.6×10^{-13} N directed out of the plane

b. 1.6×10^{-13} N directed into the plane

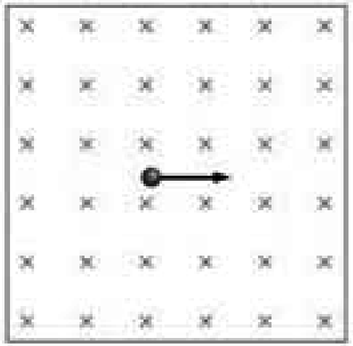
c. $\sqrt{3} \times 10^{-13}$ N directed out of the plane

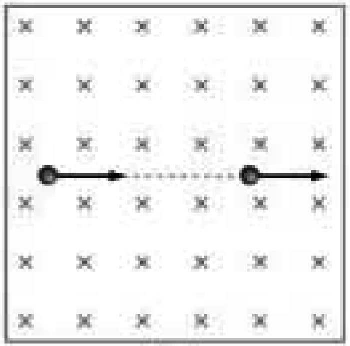
d. there is no magnetic force on the particle

$F = qBv_\perp$

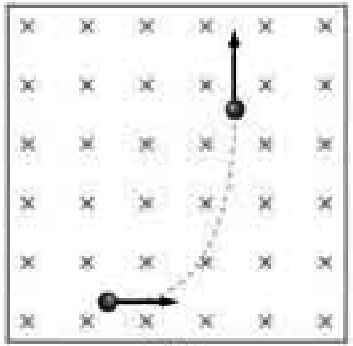

q < 0
B
v
q
q = 0
q > 0

The figure at right shows the instantaneous velocity of a positively charged particle within a uniform magnetic field. Particle velocity is perpendicular to the magnetic field (directed into the plane). Which of the following images best represents possible subsequent motion of the particle?

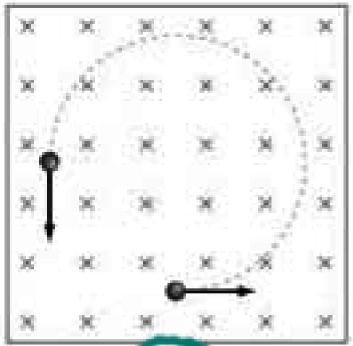




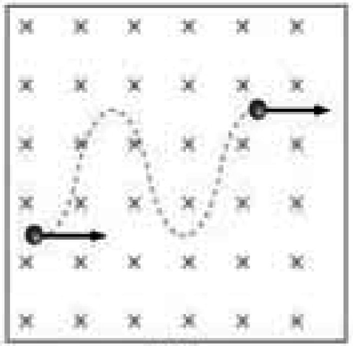
(a)



(b)



(c)

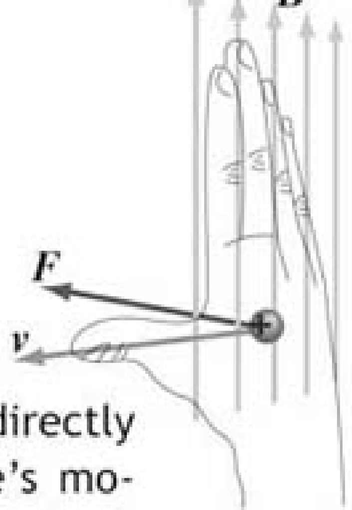


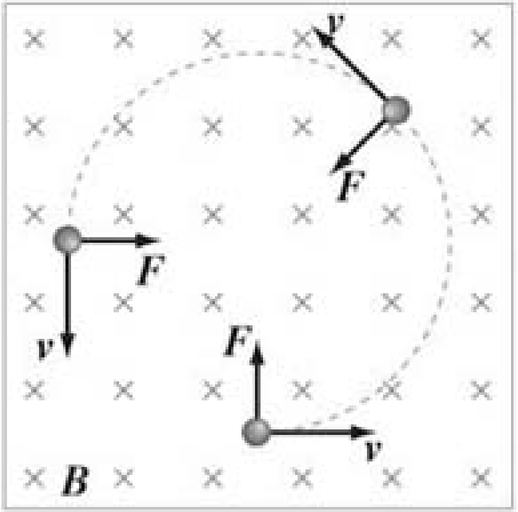
(d)

The answer is (c)

The magnetic force is perpendicular both to the particle velocity and to the magnetic field. The particle moves in a circle. The magnetic force is a *centripetal force*.

$$F = qvB = \frac{mv^2}{r}$$





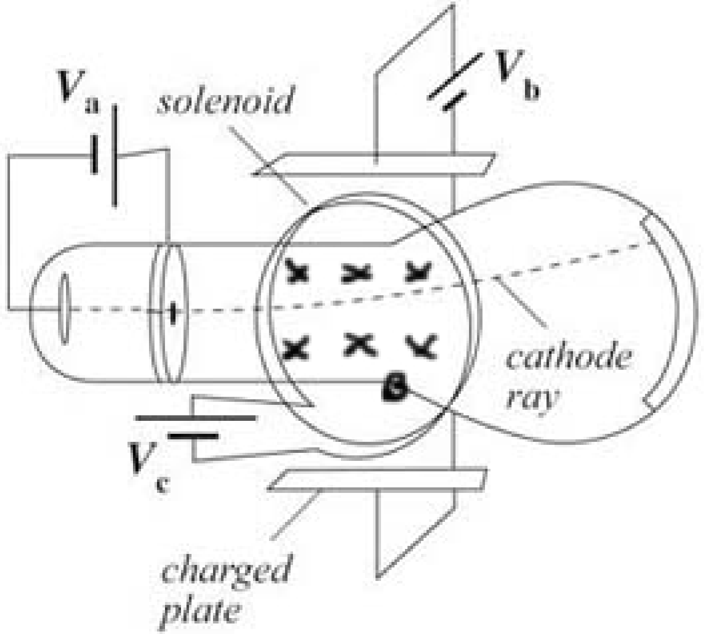
The radius of the circle is directly proportional to the particle's momentum, and inversely proportional to the charge and magnetic field strength.

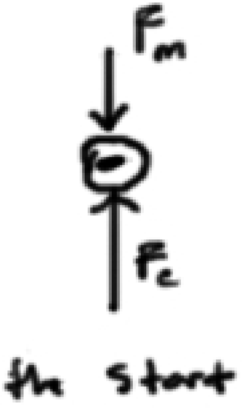
$$r = \frac{mv}{qB}$$

The angular frequency of a particle trapped in circular motion within a uniform magnetic field is called the *cyclotron frequency*.

NOTE THAT THE MAGNETIC FORCE IS PERPENDICULAR TO VELOCITY (AND INSTANTANEOUS DISPLACEMENT), SO A STEADY MAGNETIC FIELD DOES NO WORK ON A CHARGED PARTICLE. ITS DIRECTION CHANGES, BUT WITH NO DISSIPATION, KINETIC ENERGY IS CONSTANT.

The magnetic force produced by the solenoid current upon the cathode ray at right opposes the electrostatic force produced by the charged plates. Which of the following by itself could straighten the beam so that it strikes the center of the phosphorescent screen?





I. Increasing V_a

II. Decreasing V_a

III. Increasing V_b

IV. Increasing V_c

a. II only

b. IV only

c. I or IV

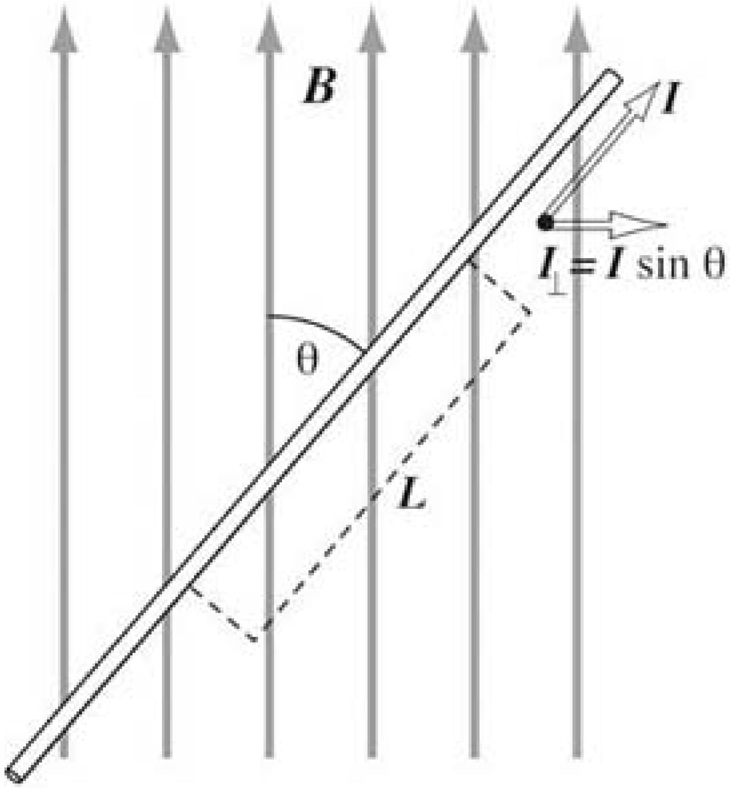
d. I, II or III

Magnetic Force on a Segment of Current Carrying Wire

$$F = L\,B\,I \sin\theta$$

Supplemental

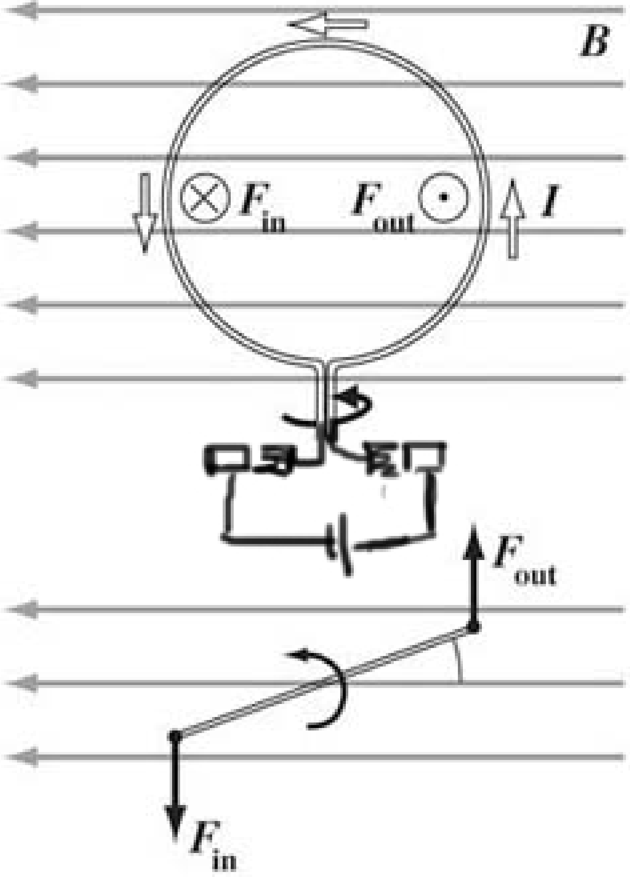
F = magnetic force on wire segment
L = segment length
B = magnetic field strength
I = current
θ = angle between the current and the magnetic field



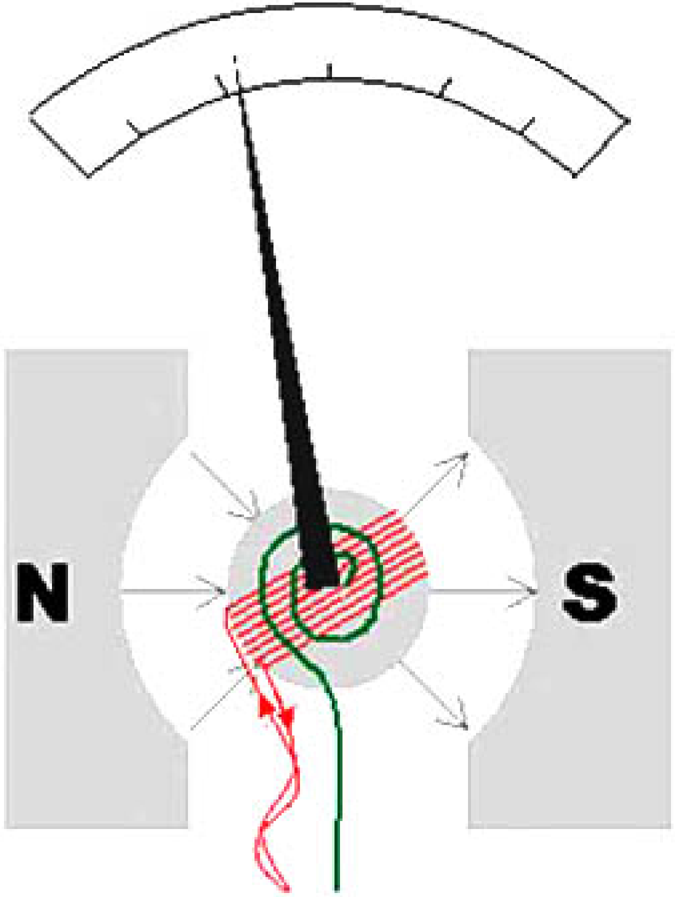
Magnetic force is directed out of the plane of the image.

Torque on a Current Loop within a Uniform Magnetic Field

$$\tau = IAB \cos \phi$$

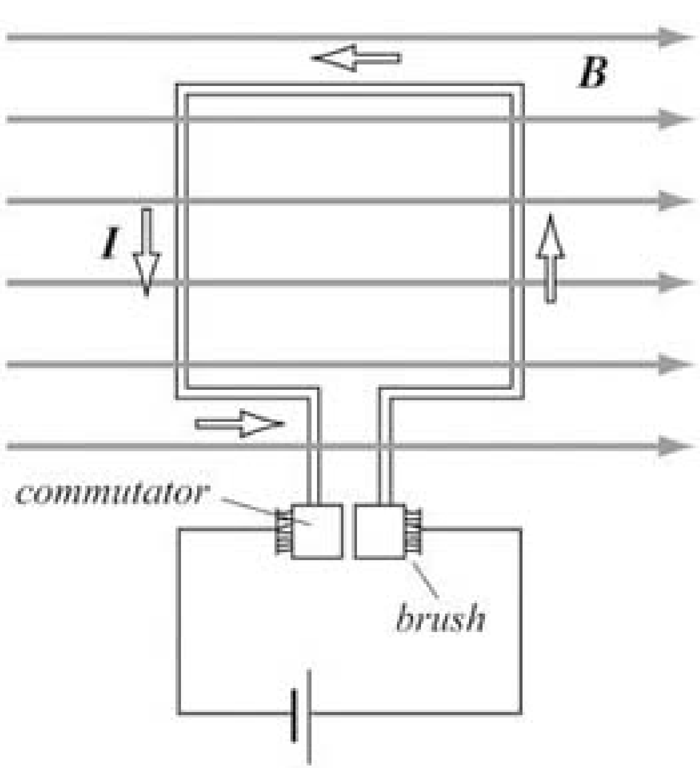


τ = torque on current loop
I = current
A = area of loop
B = magnetic field strength
ϕ = angle between the loop plane and the magnetic field



galvanometer to measure current

From the point of view depicted in the figure at right, which of the following occurs when current is supplied to the loop at right?



a. the loop rotates clockwise

b. the loop rotates counter-clockwise

c. the loop is compressed

d. there is no net torque on the loop

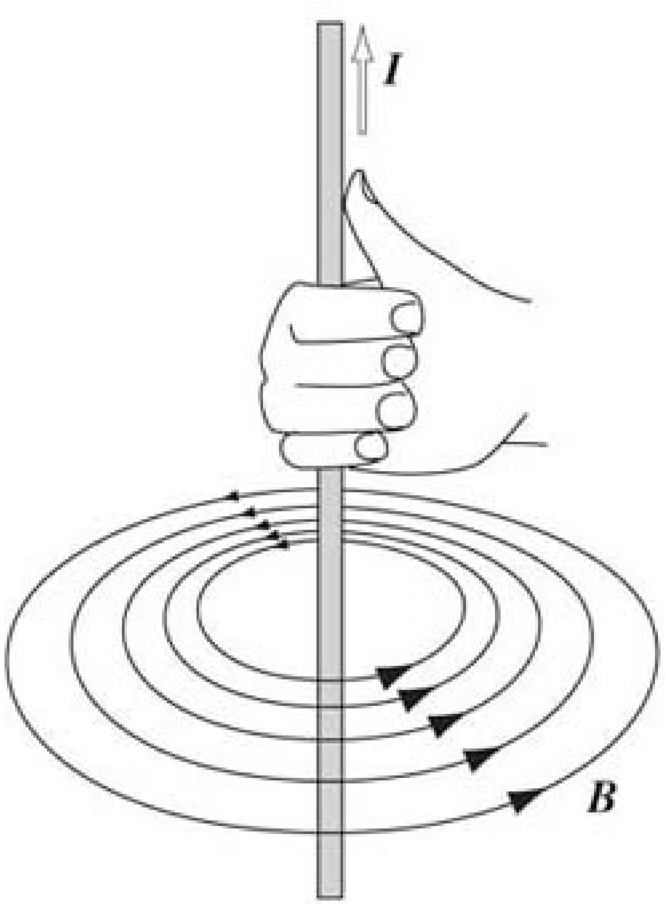
Magnetic Field of a Straight Current Carrying Wire

$$B = \frac{\mu_0 I}{2\pi d}$$

B	=	magnetic field strength at distance d
I	=	current
μ_0	=	pemeability of free space ($4\pi \times 10^{-7}$ T m/A)
d	=	distance from the wire

Ampere's Law

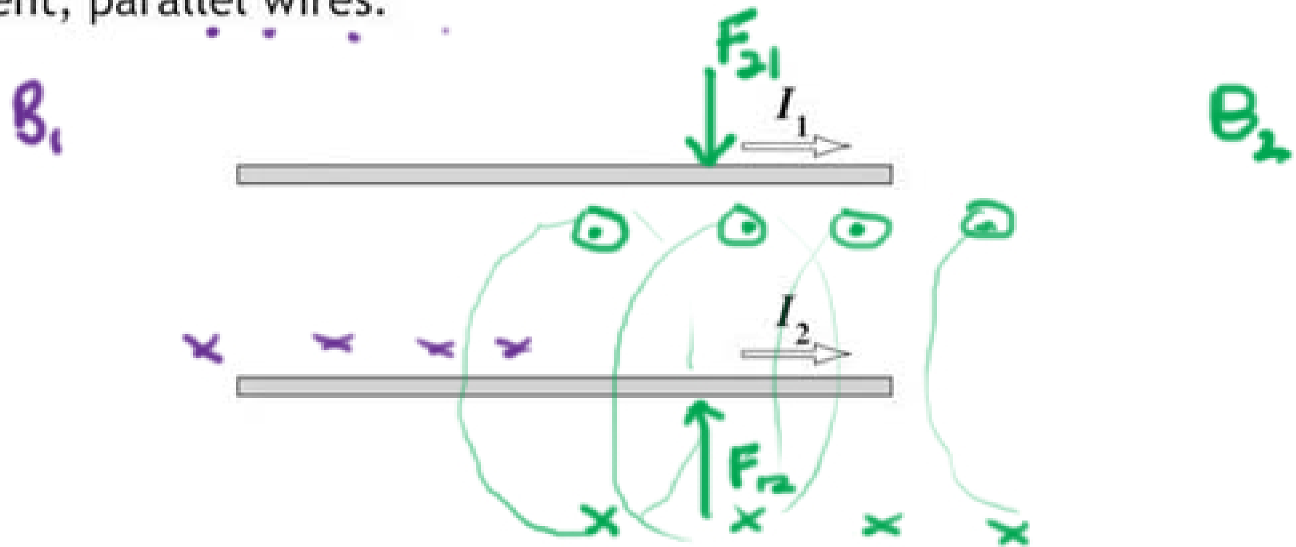
For any closed loop path, the sum of the products of the length elements and the magnetic field in the direction of the length elements is proportional to the electric current enclosed in the loop (magnetic permeability, μ_0, is the constant of proportionality).



2nd right hand rule

to determine the magnetic field of a current.

When electric current is flowing in the same direction through two, adjacent, parallel wires:



a. The wires attract each other

b. The wires repel each other

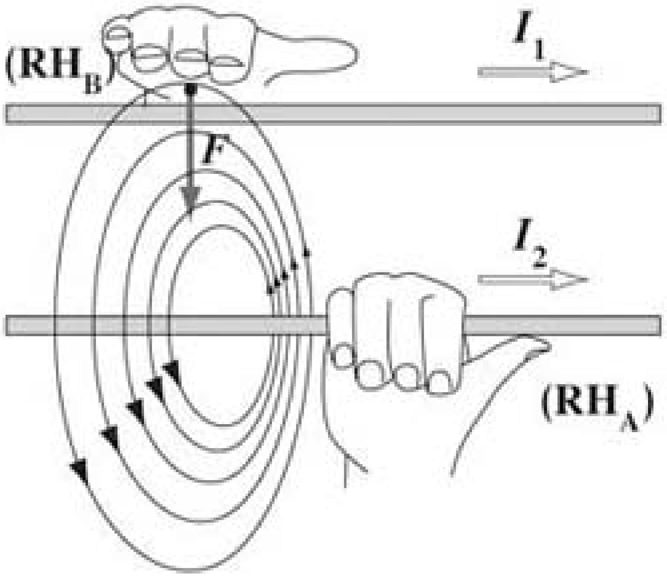
c. The wires do not interact

d. The wires generate an alternating current

The answer is a

Use both right hand rules: Use the first rule, ($\mathbf{RH_A}$), to predict the orientation of a field produced by the current of one of the wires. The second rule, ($\mathbf{RH_B}$), predicts the orientation of the magnetic force (of course, each wire feels an equal and opposite attractive force).

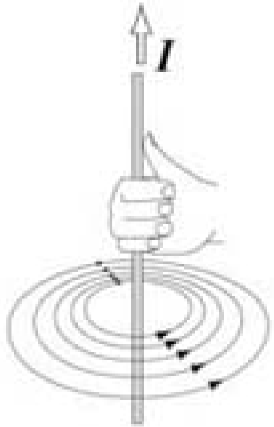
With your thumb of your right hand in the direction of the component of the current that is perpendicular to the magnetic field from the other wire and your fingers in the direction of that field, the direction of the magnetic force is out of your palm.



Point the thumb of your right hand in the direction of positive current, then wrap your fingers around the wire to show orientation of the magnetic field.

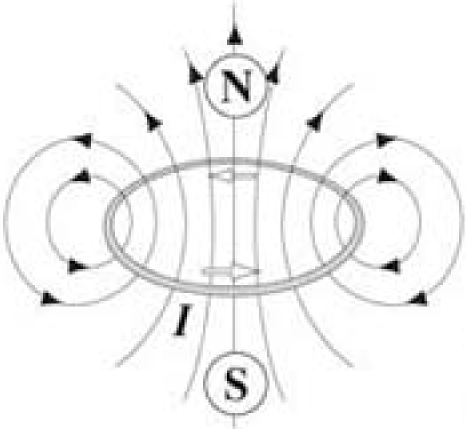
PARALLEL WIRES WITH CURRENT IN THE SAME DIRECTION ATTRACT EACH OTHER. PARALLEL WIRES WITH CURRENT IN THE OPPOSITE DIRECTION REPEL EACH OTHER. PERPENDICULAR WIRES DO NOT INTERACT.

Magnetic Fields Produced by Various Current Geometries



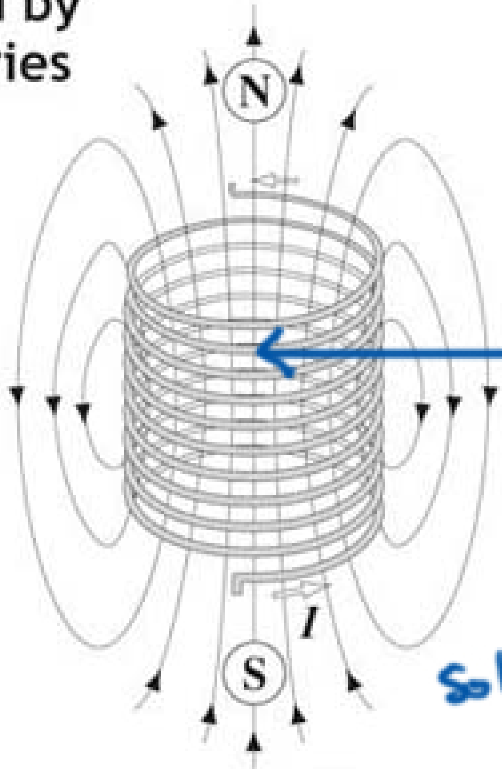
$$B = \frac{\mu_0 I}{2\pi d}$$

B = magnetic field strength
I = current
μ_0 = pemeability of free space ($4\pi \times 10^{-7}$ T m/A)
d = distance from the wire



$$B = \frac{\mu_0 I}{2r}$$

B = magnetic field strength at loop center
r = radius



inside is a uniform magnetic field

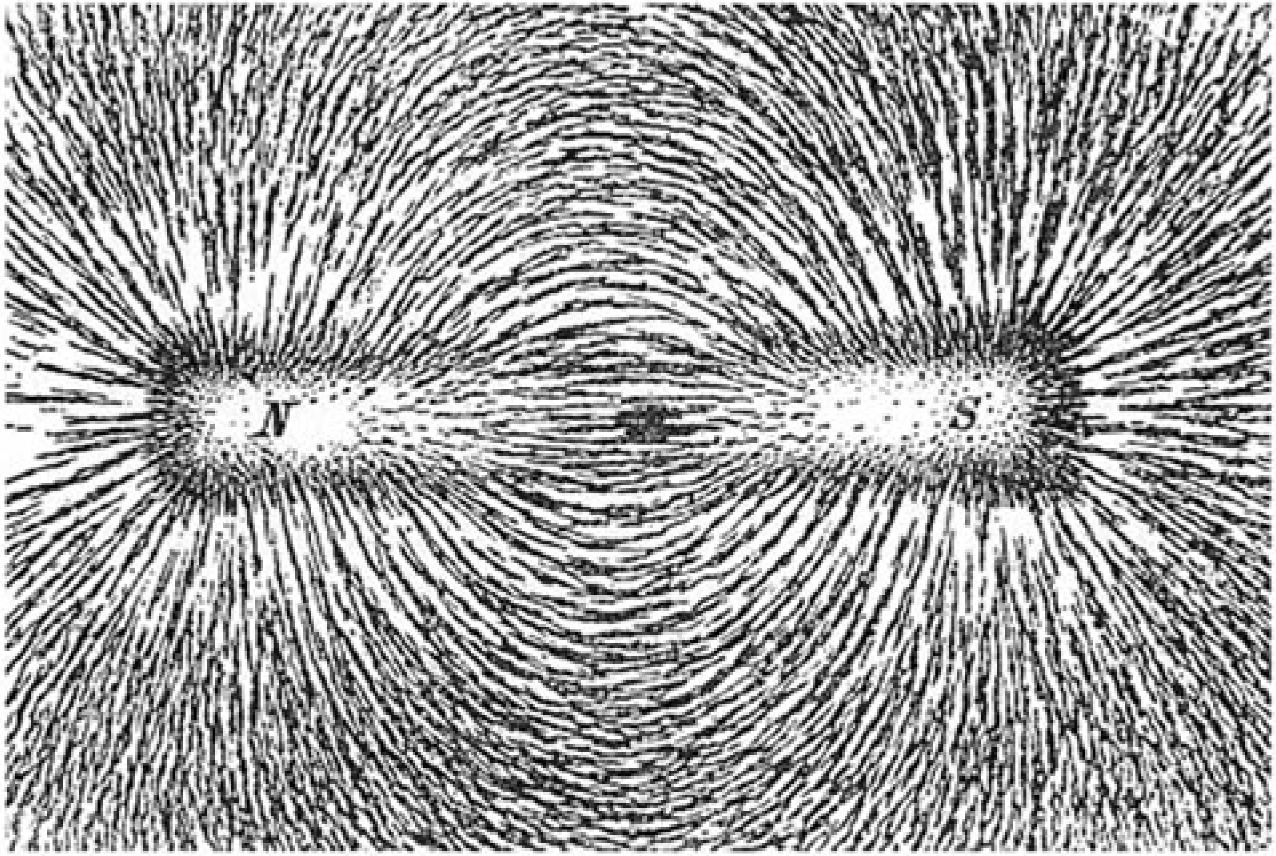
solenoid

$$B = n\mu_0 I$$

B = magnetic field strength within the solenoid
n = turns per unit length

formulas are supplementary

Magnetism in matter



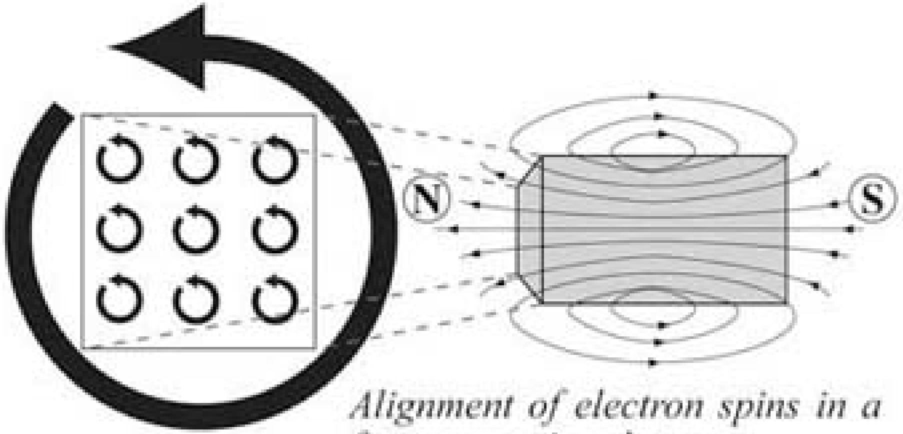
Magnetism in Matter

Paramagnetism

Paramagnetic substances contain electrons within atomic or molecular orbitals that are unpaired, producing net electron spin. Paramagnetic substances are weakly attracted by magnetic fields.

Ferromagnetism

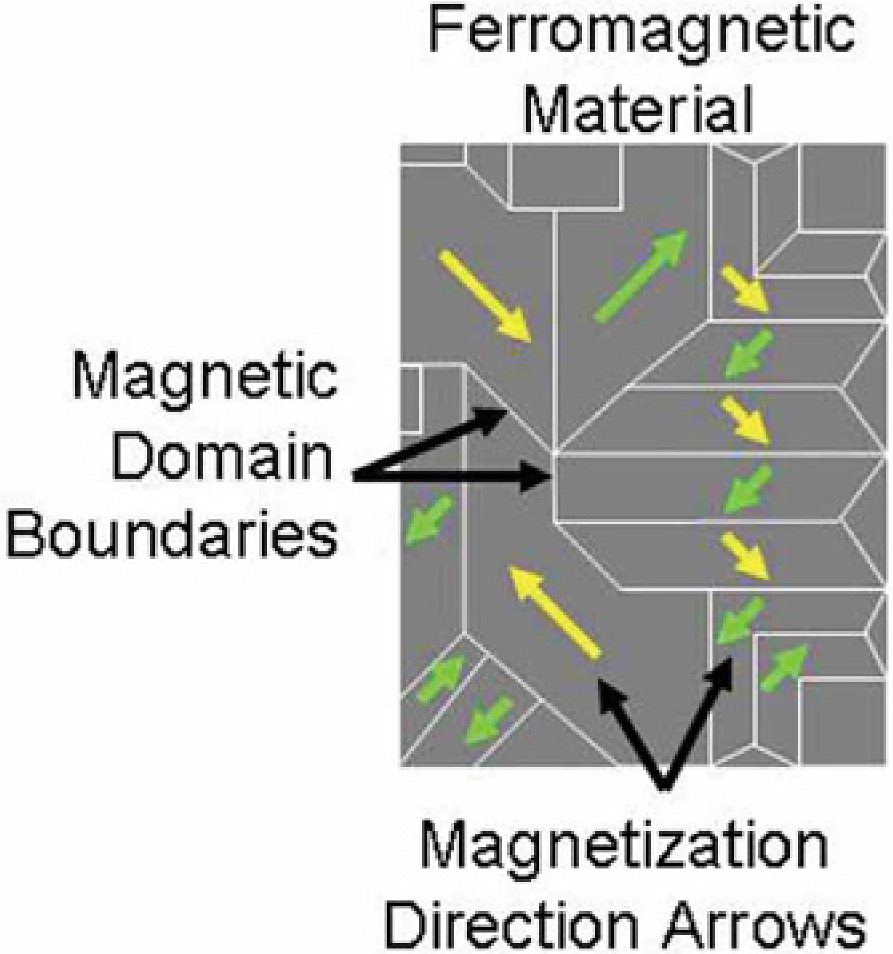
Ferromagnetic substances can be permanently magnetized as randomly oriented electron spins align cooperatively in domains. Ferromagnetism is much stronger than paramagnetism.

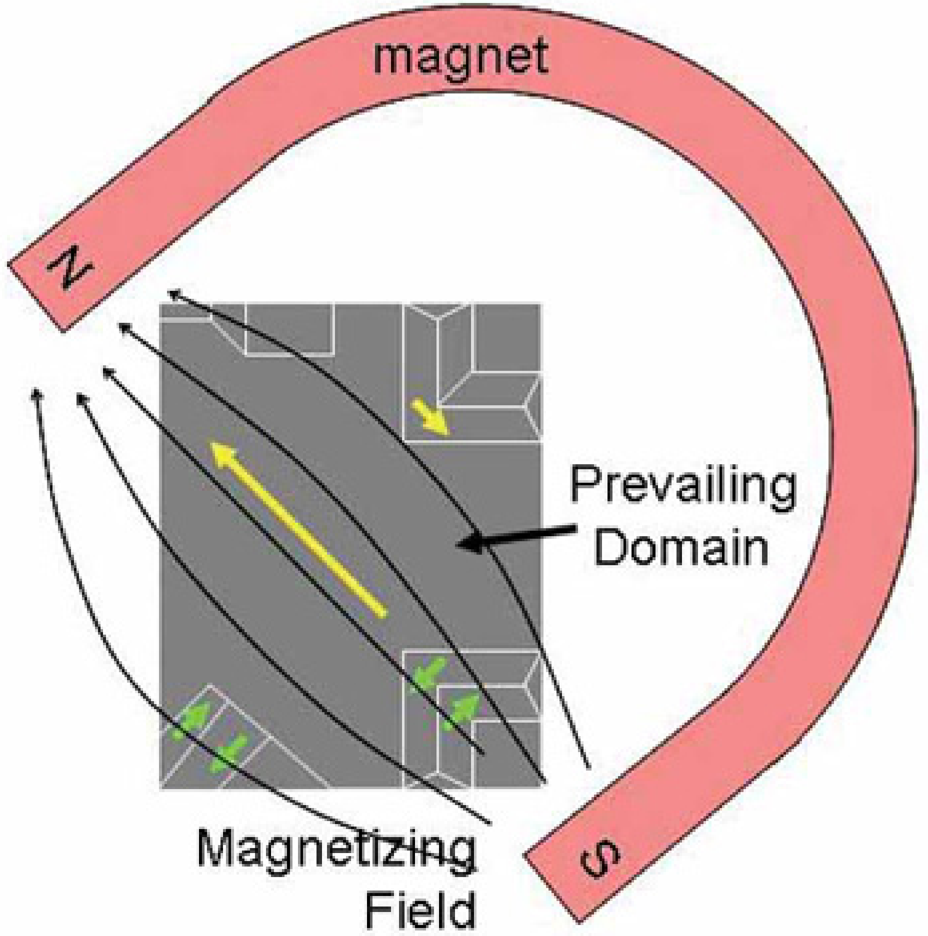


Alignment of electron spins in a ferromagnetic substance.

Diamagnetism

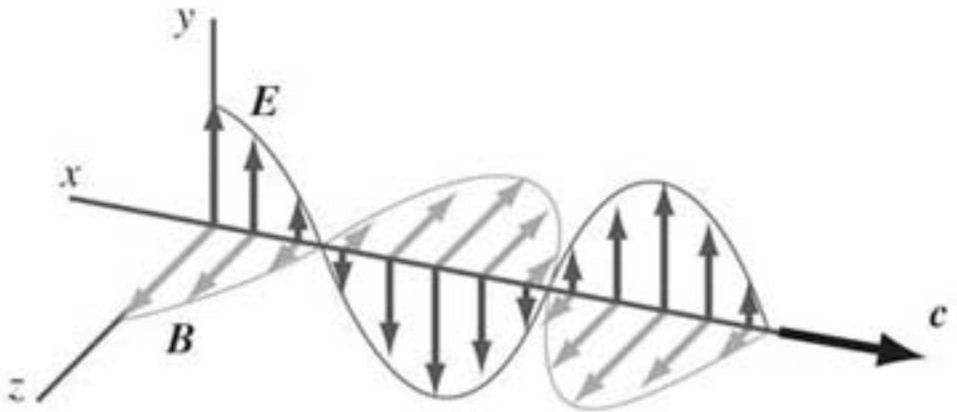
In diamagnetic substances all electrons are paired. Diamagnetic substances are very, very weakly repelled by magnetic fields, a much weaker interaction than either paramagnetism or ferromagnetism.


Ferromagnetic Material
Magnetic Domain Boundaries
Magnetization Direction Arrows


magnet
N
S
Prevailing
Domain
Magnetizing
Field

Properties of Light

Electromagnetic Wave Propagation



- transverse waves

$c = 3.0 \times 10^{8}$ m/s

Which of the following distinguishes electromagnetic waves from sound waves?

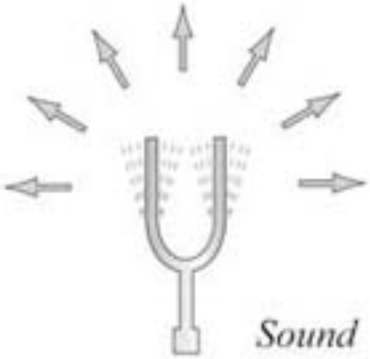
a. Electromagnetic waves are longitudinal. Sound waves are transverse.

b. Electromagnetic waves do not require a medium.

c. Electromagnetic waves carry energy.

d. Electromagnetic waves can't be polarized.

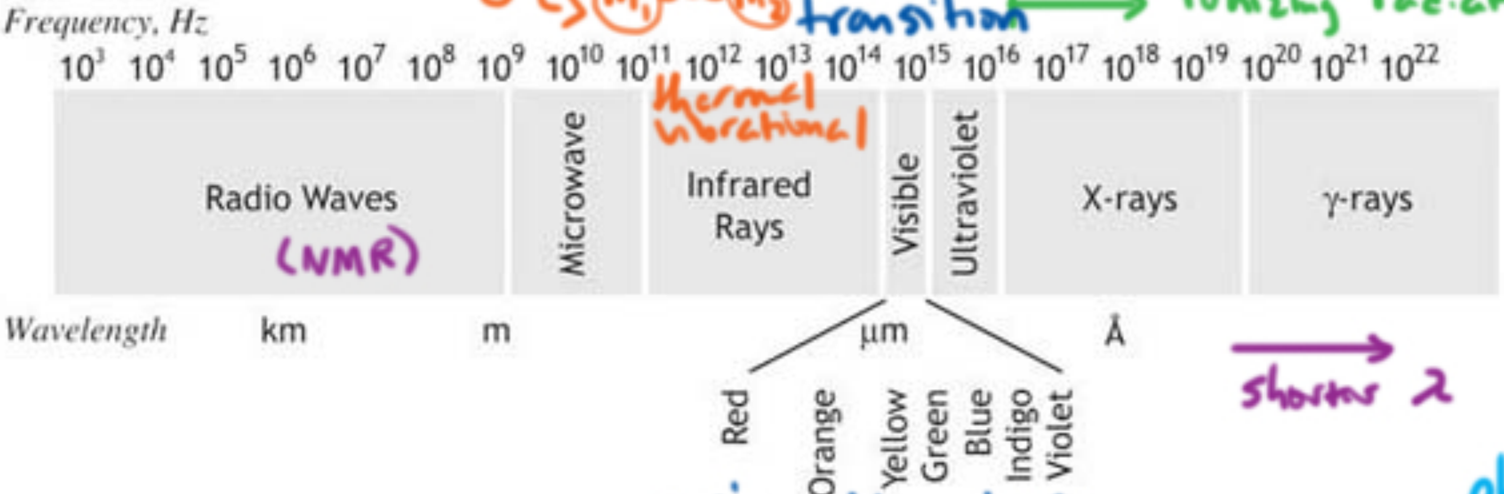
Light



Sound

The Electromagnetic Spectrum

$E = hf$



- pigments
- crystal field splitting

LUMO / HOMO — UV absorbance

UV → visible — fluorescence

- phosphorescence
- chemiluminescence

photoelectric effect

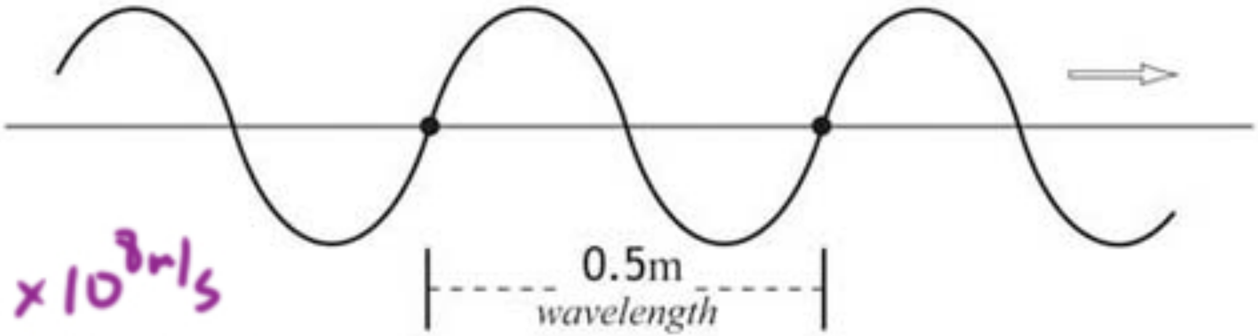
$KE = hf - \phi$

$$c = f\lambda$$

$$= 3 \times 10^8 \ \frac{m}{s}$$

c = speed of light
f = frequency
λ = wavelength

A radio wave travelling through space has a wavelength of 0.5m. What is the frequency of the wave?



$v = f\lambda$

$c = f\lambda$

Divide either f or λ into wave speed to get the other.

$$f = \frac{3 \times 10^8 \, m/s}{0.5 \, m}$$

$$\frac{3 \times 10^8}{5 \times 10^{-1}} = 0.6 \times 10^9 = 6 \times 10^8$$

a. 150 MHz

b. 250 MHz

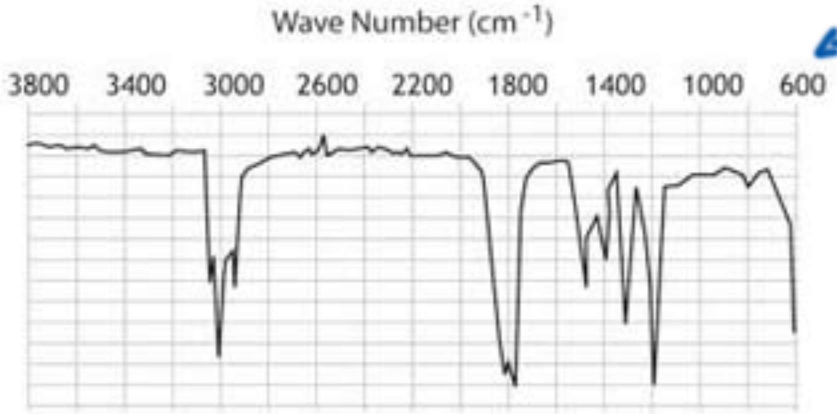
c. 300 MHz

d. 600 MHz (circled)

$MHz = 10^6 \, Hz$

Infrared spectroscopy is a technique to identify an unknown compound by assaying the absorption of frequencies of infrared radiation matching the vibrational frequencies associated with the chemical bonds within the substance.

Infrared spectrographs usually represent absorption frequencies as *wave numbers* (cm^{-1}). Wave numbers are reciprocal values of the wavelengths of absorbed radiation.



The unknown substance depicted by the spectrograph above has a strong absorbance at 3000 cm^{-1}. What is the frequency in Hz of this peak?

$(3000\,\mathrm{cm}^{-1})(3.0 \times 10^{10}\,\mathrm{cm/s})$

a. 1×10^{-5} Hz b. 1×10^{7} Hz c. 9×10^{11} Hz d. 9×10^{13} Hz

assume $v = c$

wave numbers $k = \frac{1}{\lambda}$

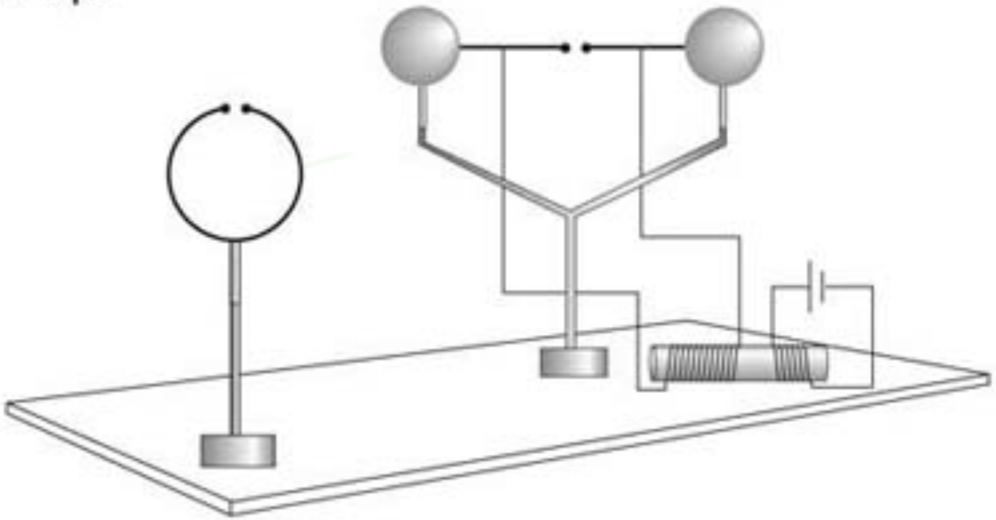
$\lambda = \frac{\text{meters}}{\text{cycle}}$

$k = \frac{\text{cycles}}{\text{meter}}$ or $\frac{\text{cycles}}{\text{cm}}$ or cm^{-1}

$v = \lambda f$ $f = \frac{v}{\lambda}$

$f = kv$

When sufficient voltage is supplied to the induction coil in the apparatus below, an oscillatory discharge occurs across the spark gap between the two electrode spheres. The oscillatory discharge occurs at the resonance frequency of the induction coil/electrode combination, an LC circuit, at approximately 1 X 10^8 Hz. When the resonance frequency of a nearby conducting loop with its own spark gap is adjusted to match this frequency, sparks are observed across the gap in the nearby loop, even though the loop is not touching the induction coil/electrode apparatus. What are being transmitted by the coil/electrode apparatus to the loop to cause sparking in the loop?



a. cathode rays

b. radio waves

c. alpha particles

d. x-rays

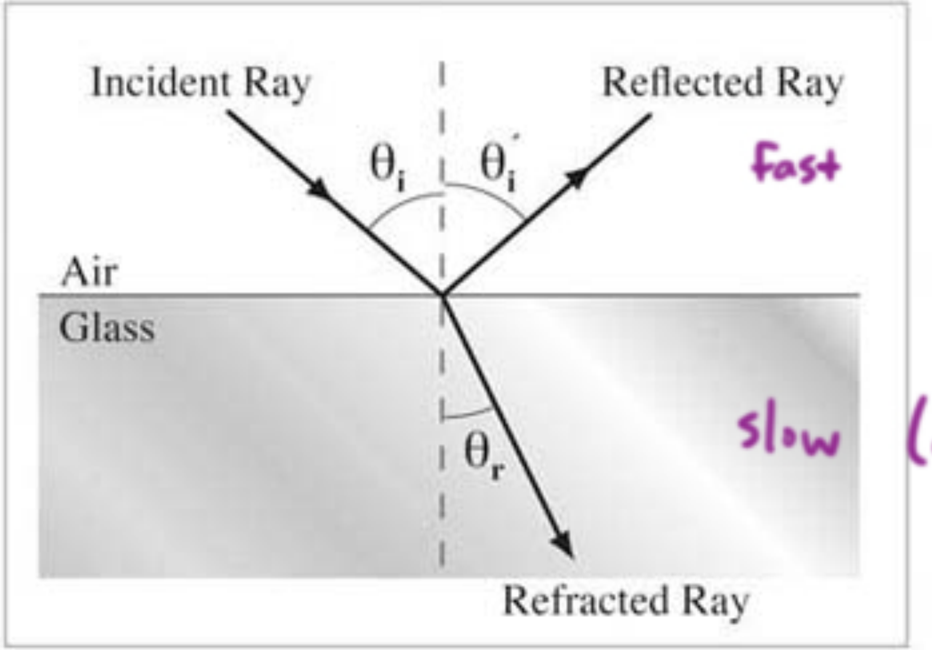
Reflection and Refraction

$n = \frac{c}{v}$

Law of Reflection

$$\theta_i = \theta_i'$$

θ_i = angle of incidence
θ_i' = angle of reflection



(n ~ 1.5)

Snell's Law Governing Refraction

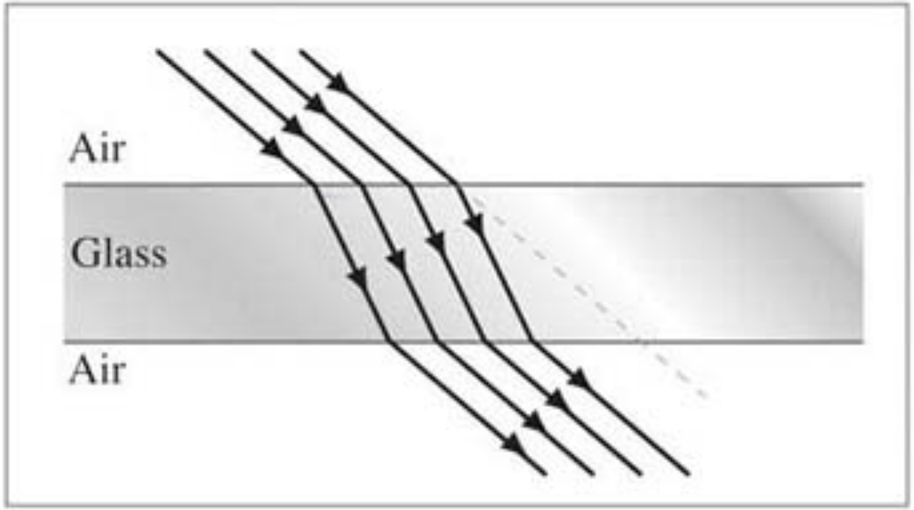
$$n_1 \sin\theta_i = n_2 \sin\theta_r$$

n_1 = index of refraction in first medium
θ_i = angle of incidence
n_2 = index of refraction in second medium
θ_r = angle of refraction

Index of Refraction

$$n = \frac{c}{v}$$

n = index of refraction of medium
c = speed of light in a vacuum
v = speed of light in the medium



$$\frac{v_2}{v_1} = \frac{n_1}{n_2} \qquad \frac{\lambda_2}{\lambda_1} = \frac{v_2}{v_1} \qquad \frac{\lambda_2}{\lambda_1} = \frac{n_1}{n_2}$$

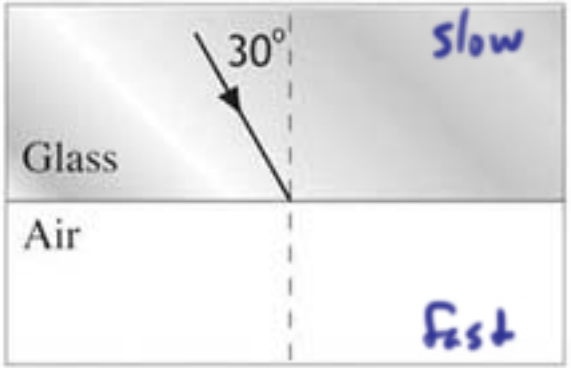
entering the new medium
- v is changed
- f doesn't change
- $v = f\lambda$

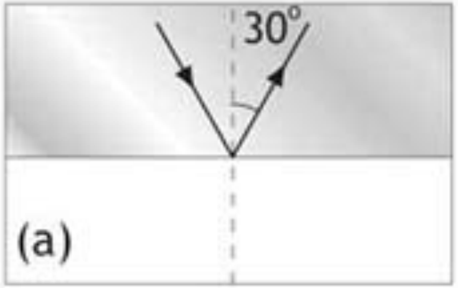
λ must change

entering a slow medium
λ shortens

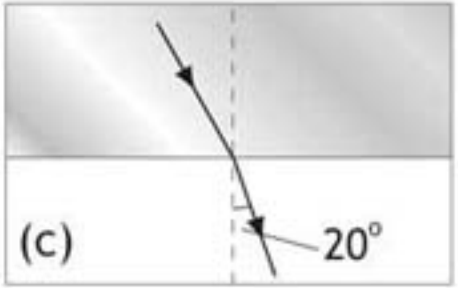
$$n_2\lambda_2 = n_1\lambda_1$$

A light ray travelling through glass (n = 1.5) is incident on the smooth, flat interface between the glass and outside air (n = 1.0). The light is travelling at an angle of 30° to the normal as pictured at right. Which results from refraction at the boundary?



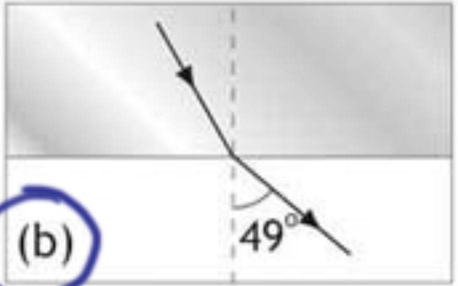


(a)

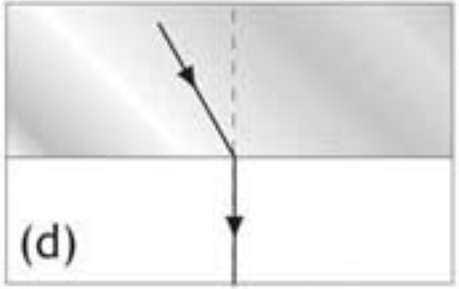


(c)

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

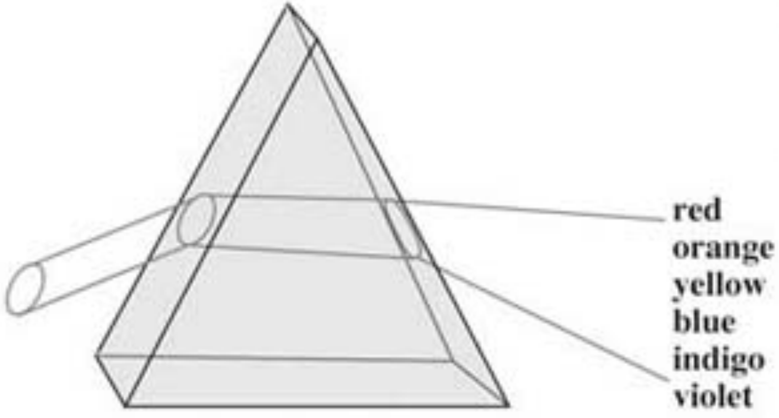


(b)


(d)

A prism disperses white light into its spectrum, revealing the colored components of white light. Which of the following accounts for this behavior?

white light



Dispersion because of slightly different index of refraction for different frequencies.

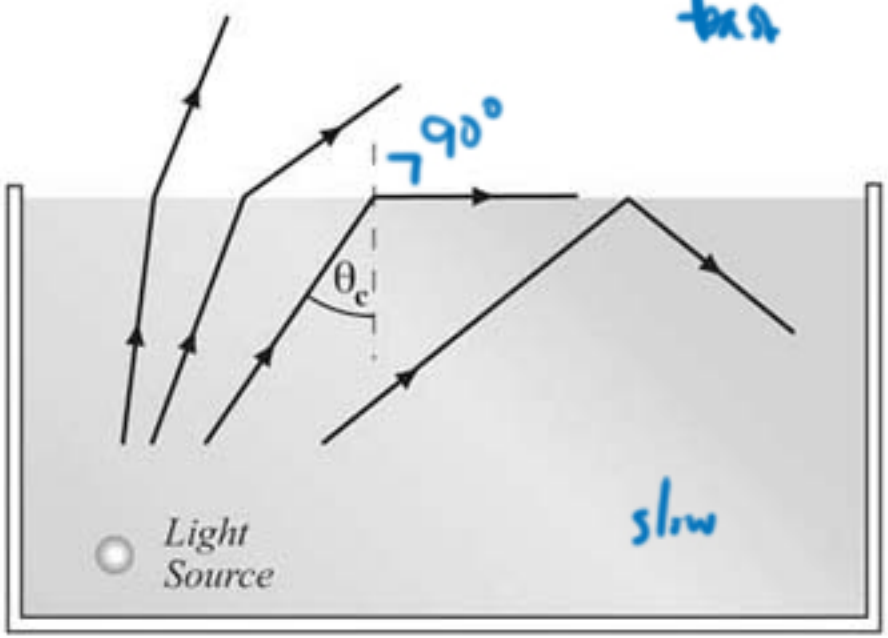
a. Red rays are refracted the most by the prism, violet rays the least.

b. The product of wavelength and frequency is the same for all colors in the glass but not in empty space.

c. Visible light of longer wavelength moves with greater speed in glass than visible light of shorter wavelength.

d. Moving from a slower to a faster media increases the wavelength of a particular light ray.

The Critical Angle and Internal Reflection



$\sin\theta_c n_1 = \sin(90^\circ) n_2$

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$(n_1 > n_2)$$

diamond

$\sin\theta_c = \frac{1}{2.5}$

$\theta_c < 30^\circ$

diamond $n_1 = 2.5$

θ_c = critical angle

n_1 = index of refraction in first medium

n_2 = index of refraction in second medium

A typical fiber optic cable consists of two concentric layers: the outer cladding and the inner core. The index of refraction of the core is higher than that of the cladding. With a straight or slightly bending fiber, the signal always strikes the core-cladding interface at an angle (from the normal) higher than the critical angle. Therefore, the light is reflected back into the fiber which allows transmission over great distance.

What is the minimum time required for the cable above to transmit a signal over a distance of 90 km?

a. 3.0×10^{-7} s

b. 2.0×10^{-4} s

c. 3.0×10^{-4} s

d. 4.5×10^{-4} s

$n = \frac{c}{v}$

$v = \frac{c}{n}$

$v = \frac{3.0 \times 10^8 \text{ m/s}}{1.5} = 2 \times 10^8 \text{ m/s}$

$\Delta x = 90 \text{ km}$

$\Delta x = 9 \times 10^4 \text{ m}$

$\frac{\Delta x}{\Delta t} = v \quad \Delta t = \frac{\Delta x}{v}$

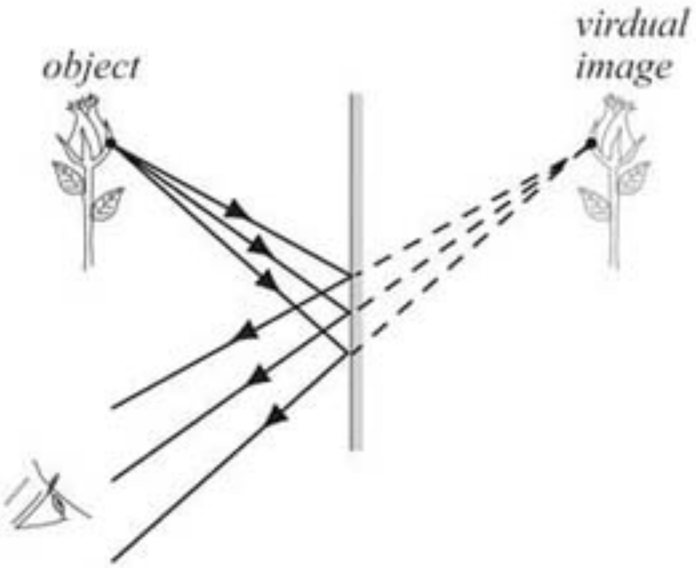
$\Delta t = \frac{9 \times 10^4 \text{ m}}{2 \times 10^8 \text{ m/s}} = 4.5 \times 10^{-4} \text{ s}$

Geometric
optics

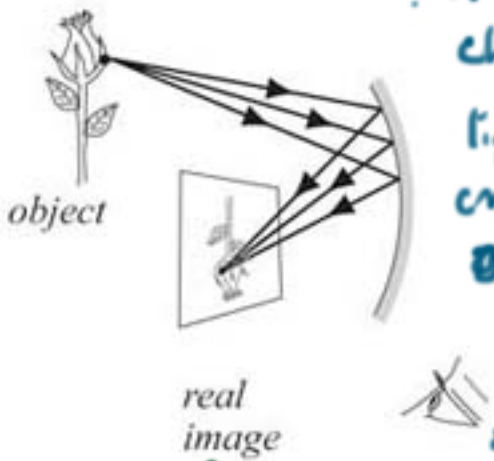
Virtual and Real Images

Optical devices where the ray approach to light is sufficient.

$$\frac{1}{F} = \frac{1}{I} + \frac{1}{O}$$



A plane mirror creates a **virtual image**, located behind the mirror.

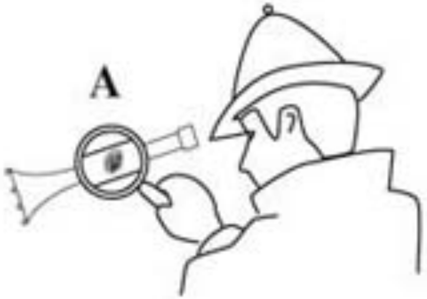


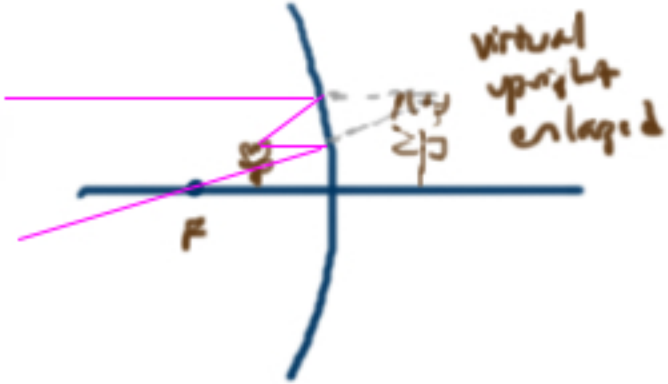
↑ an image you can cast on a screen

A **real image** is created by a concave mirror (at this object distance) which can be visualized on a screen.

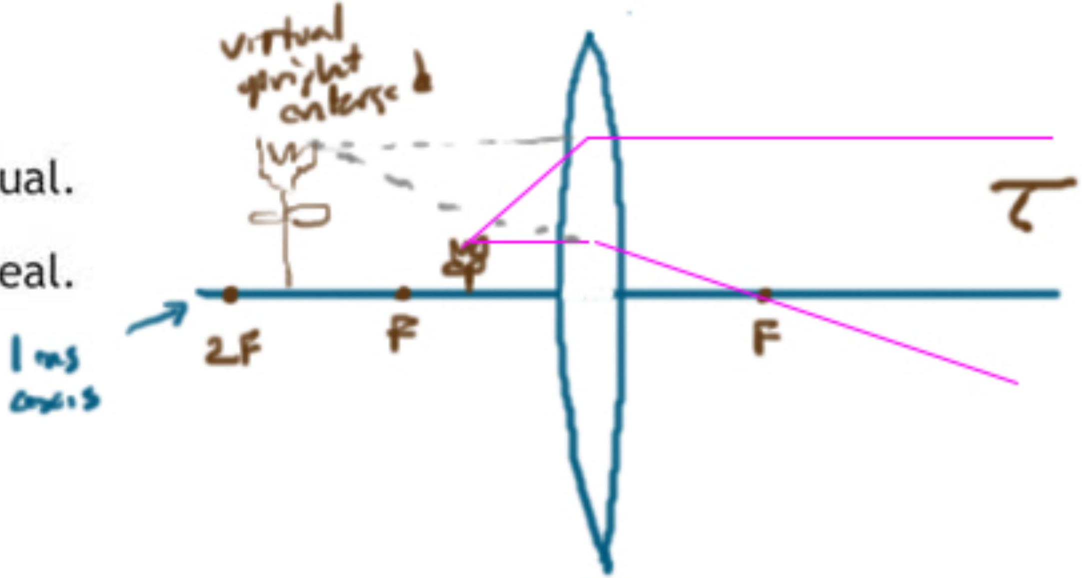
- A mirror or a lens changes the path of light so that light emanating from an object point converges on an image point or appears to emanate from a image.

A detective's magnifying glass and a concave make-up mirror are two simple optical devices that can produce enlarged images.





Which of the following statements is true about the images produced above?



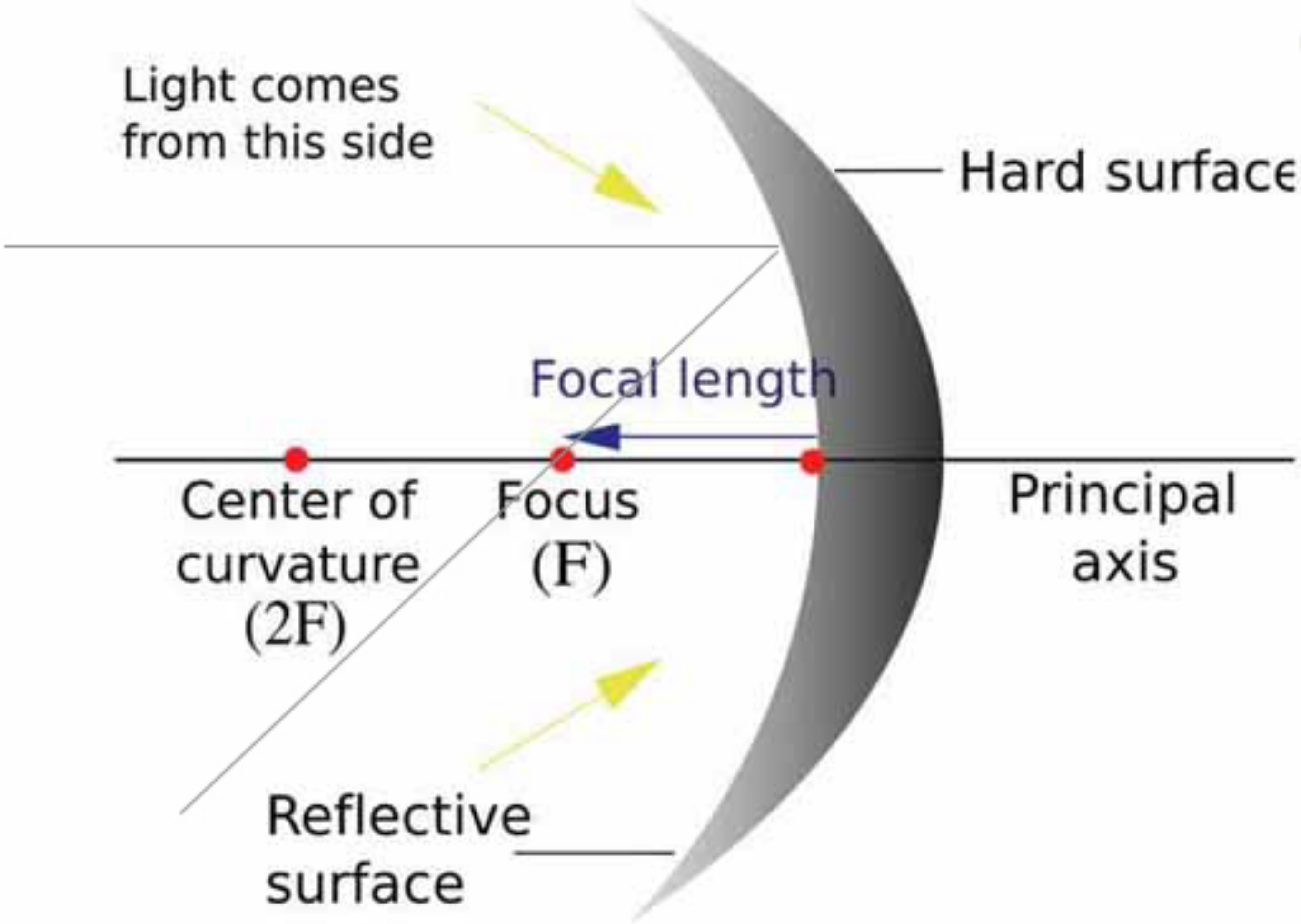
a. Image **A** is real and image **B** is virtual.

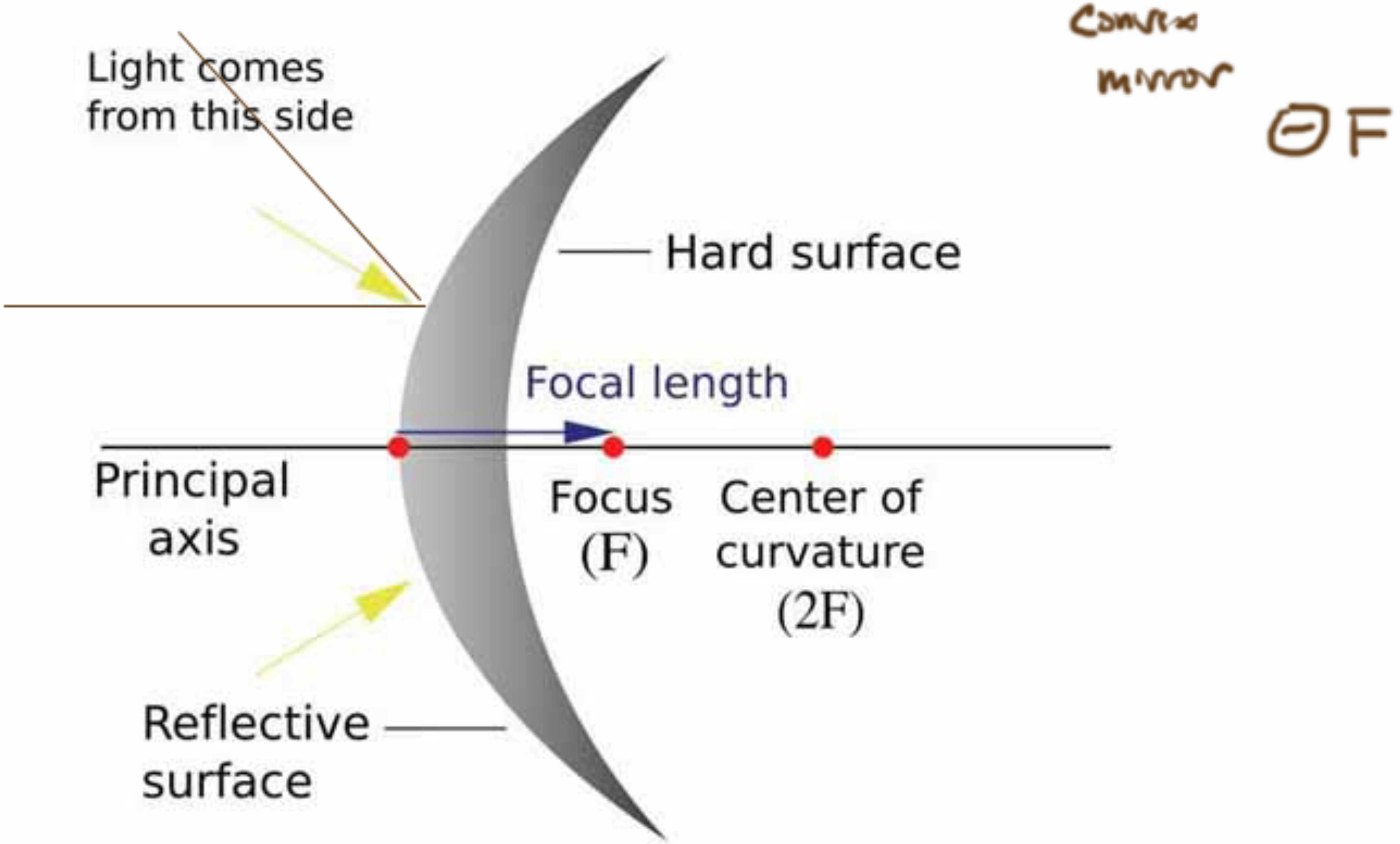
b. Image **A** is virtual and image **B** is real.

c. Both images are real.

d. Both images are virtual.

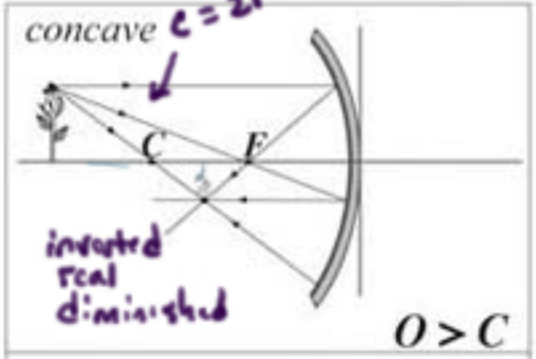
Concave mirror
⊕ F




Light comes
from this side
Hard surface
Focal length
Principal
axis
Focus
(F)
Center of
curvature
(2F)
Reflective
surface
convex
mirror
⊖F

Concave and Convex Mirrors

(+) F



C = 2F

inverted real diminished

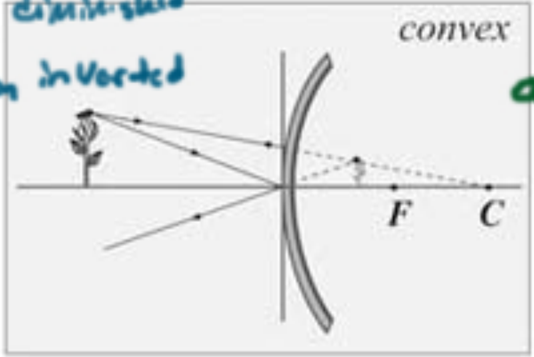
$$\frac{1}{F} = \frac{1}{I} + \frac{1}{O}$$

$$M = -\frac{I}{O}$$

|M| < 1 diminished
if (−) then inverted

C	=	center of curvature
F	=	focal length (1/2 *C*)
I	=	image distance
O	=	object distance
M	=	lateral magnification

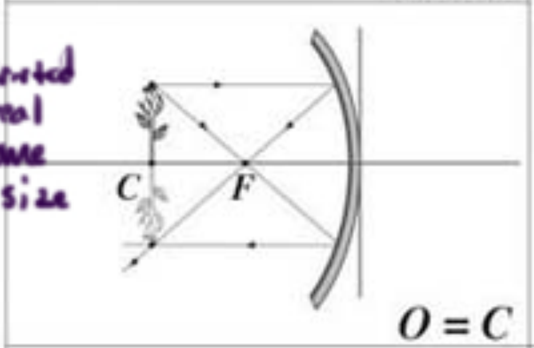
(−) F



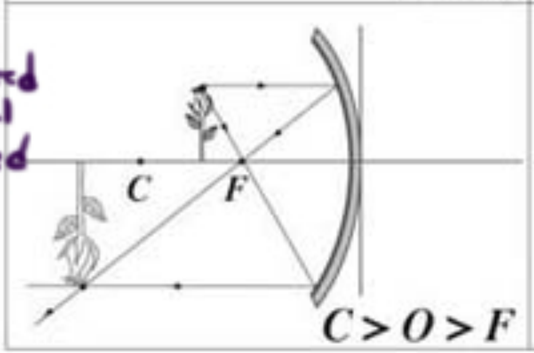
DEV (diminished, erect, virtual) with a single convex mirror.

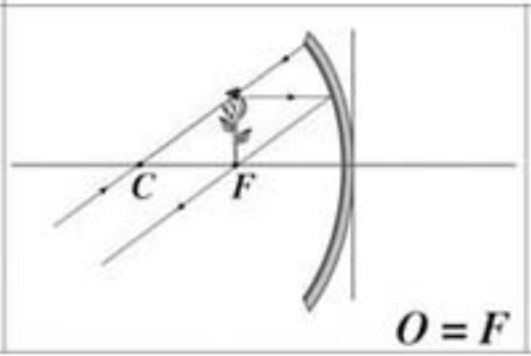
always DUV
diminished
upright
virtual

inverted real same size

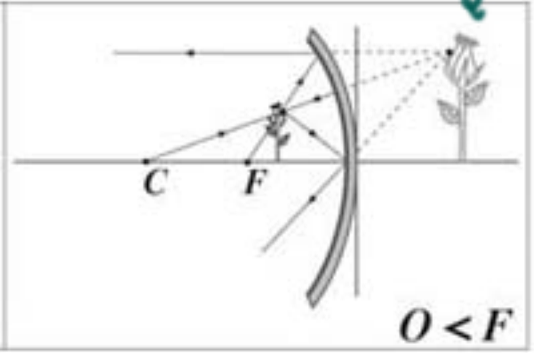


inverted real enlarged



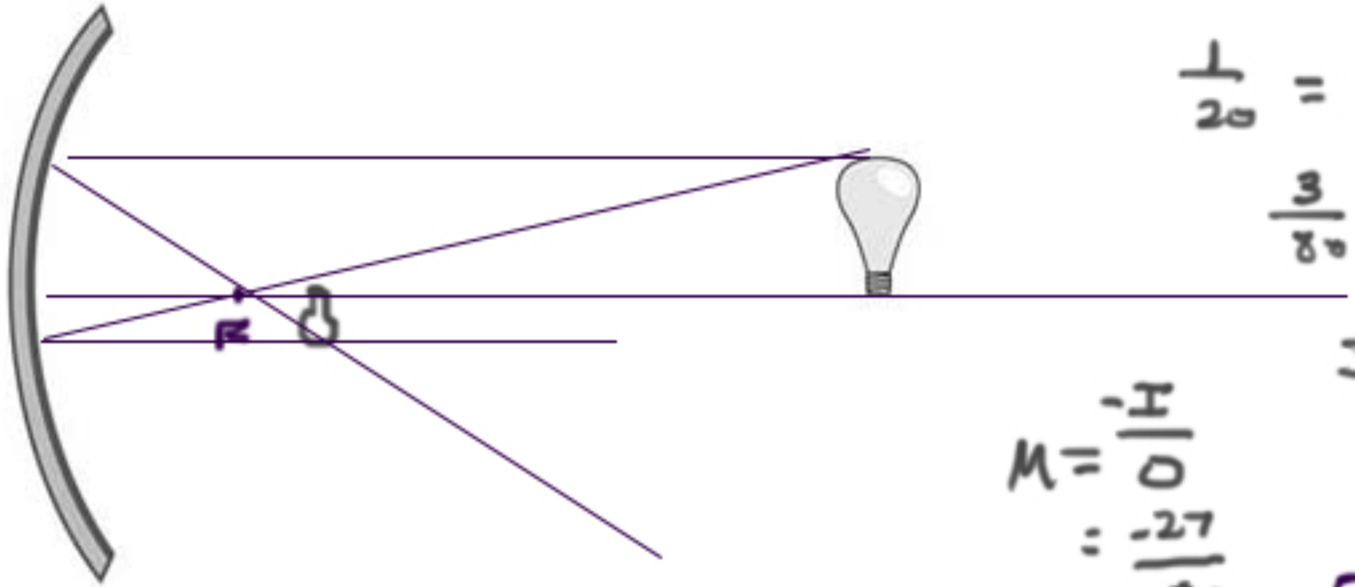


(−) image



virtual upright enlarged

A concave mirror has a focal length of 20cm. What type of image will the mirror form of a light bulb placed 80cm in front of the mirror?



$$\frac{1}{F} = \frac{1}{O} + \frac{1}{I}$$

$$\frac{1}{20} = \frac{1}{80} + \frac{1}{I}$$

$$\frac{3}{80} = \frac{1}{I}$$

$$I = 80/3 \approx 27$$

$$M = \frac{-I}{O} = \frac{-27}{80}$$

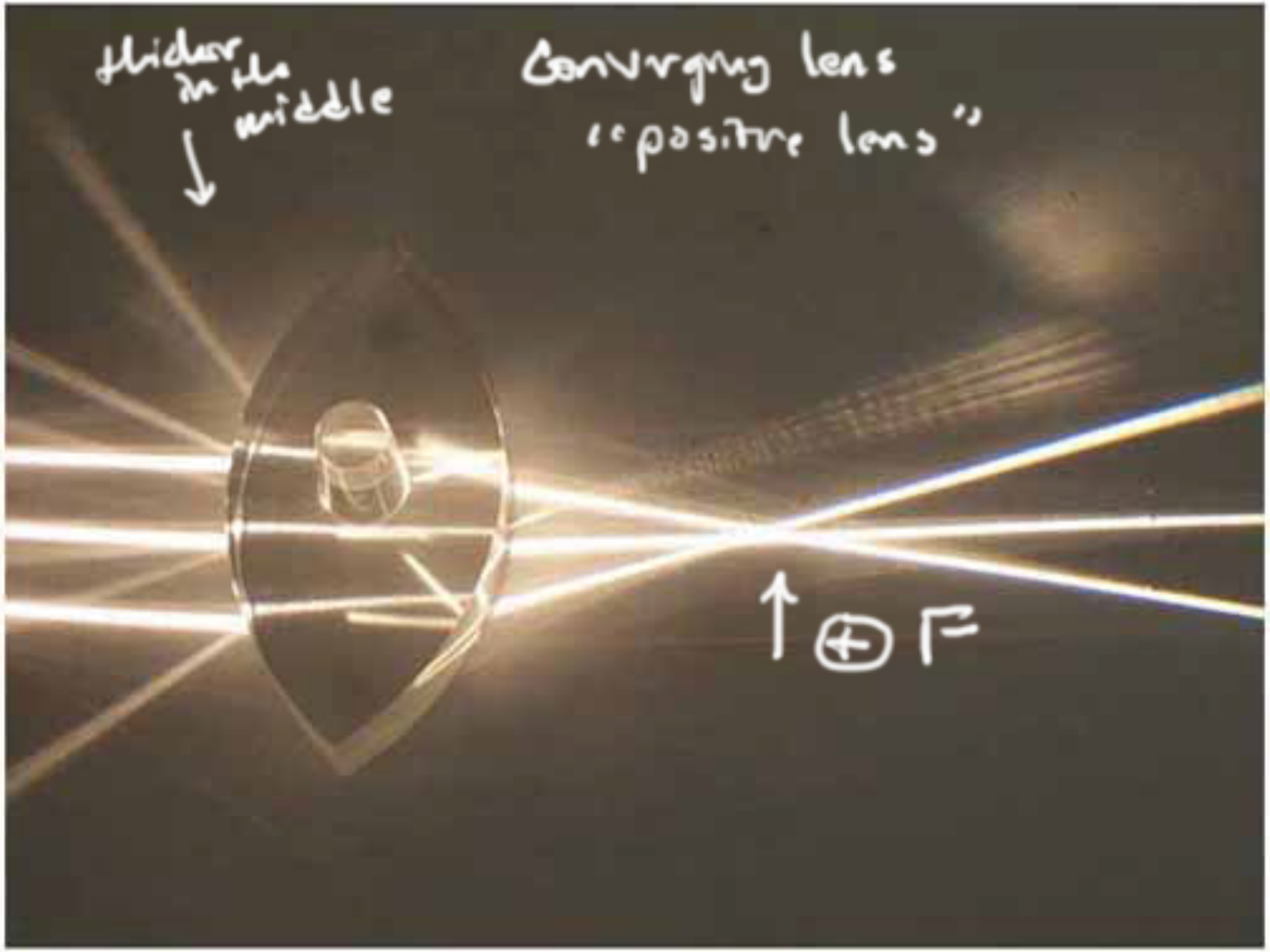
$$O > 2F$$

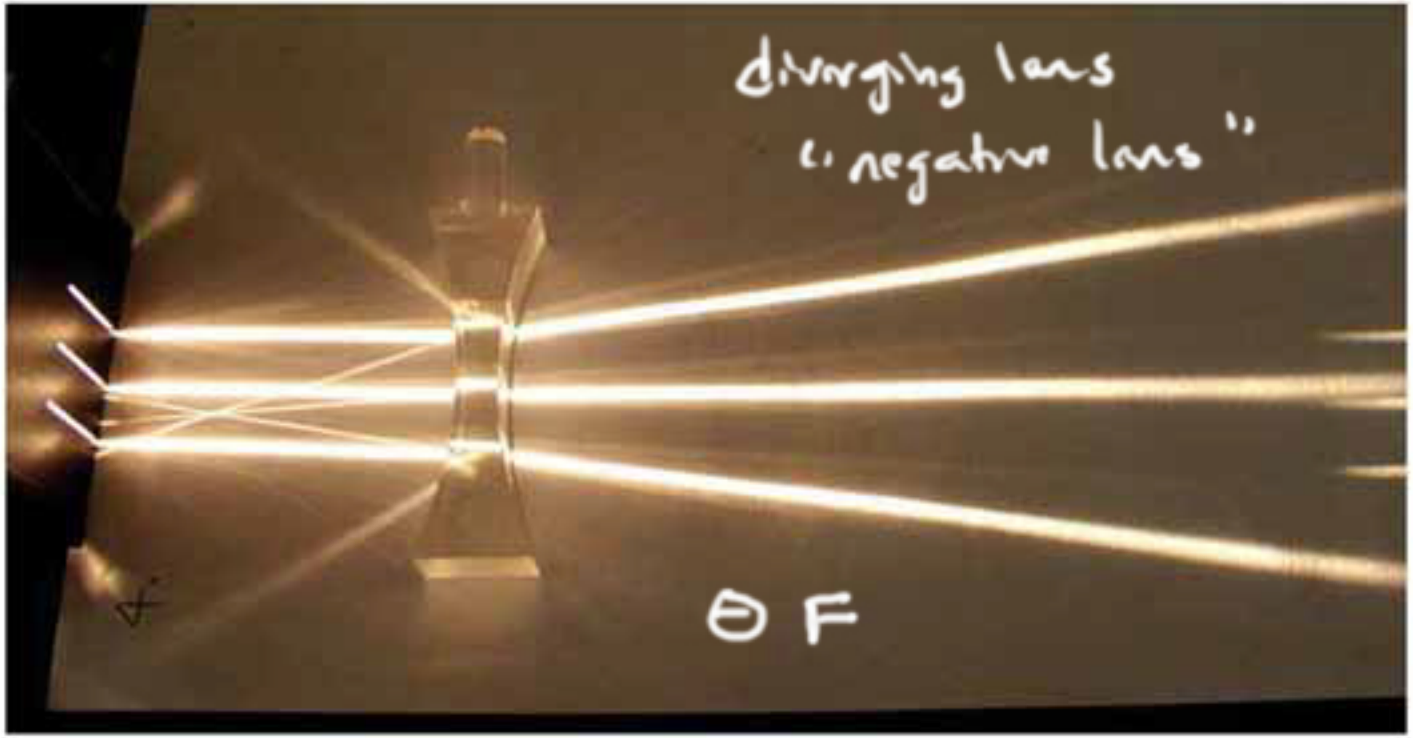
a. virtual, erect, diminished

b. real, erect, enlarged

c. real, inverted, diminished

d. virtual, inverted, enlarged


thicker in the middle
Converging lens
"positive lens"
⊕ F

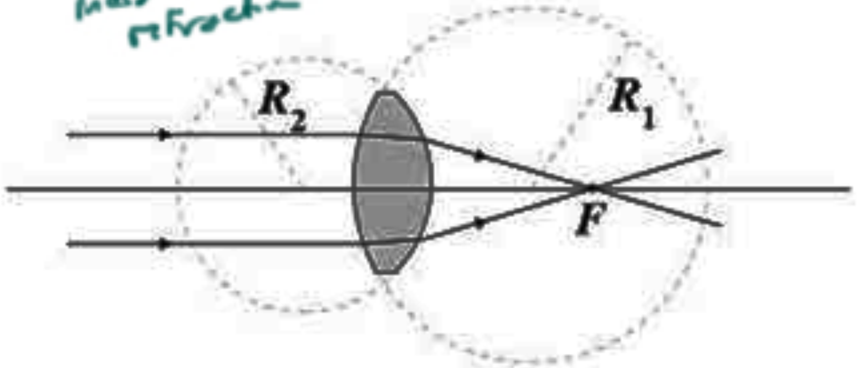

diverging lens
"negative lens"
⊖ F

Lens-Maker's Equation

$$\frac{1}{F} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

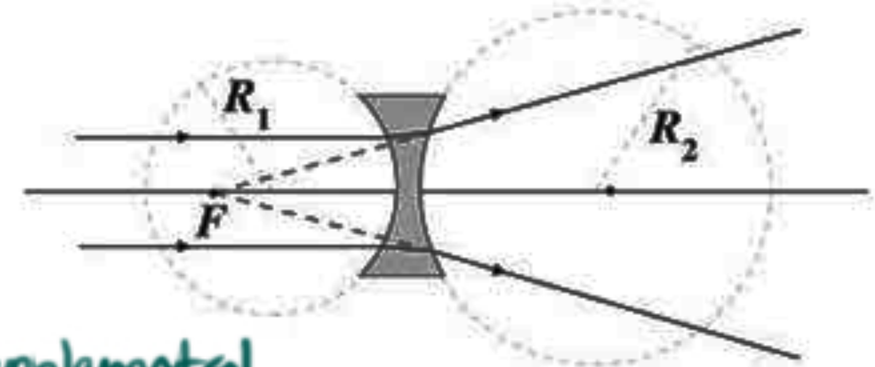
(handwritten: "material" with an arrow pointing to $(n-1)$; "shape" above $\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$; "index of refraction" with an arrow pointing to n)

F = focal length (1/2 C)
n = refractive index
R = radius of curvature



Positive (Converging) Lens

R_1 – positive
R_2 – negative
F – positive



Negative (Diverging) Lens

R_1 – negative
R_2 – positive
F – negative

Supplemental

$\frac{1}{F} \leftarrow D$ power in diopters (m^{-1})

$D = \frac{1}{I} + \frac{1}{O}$

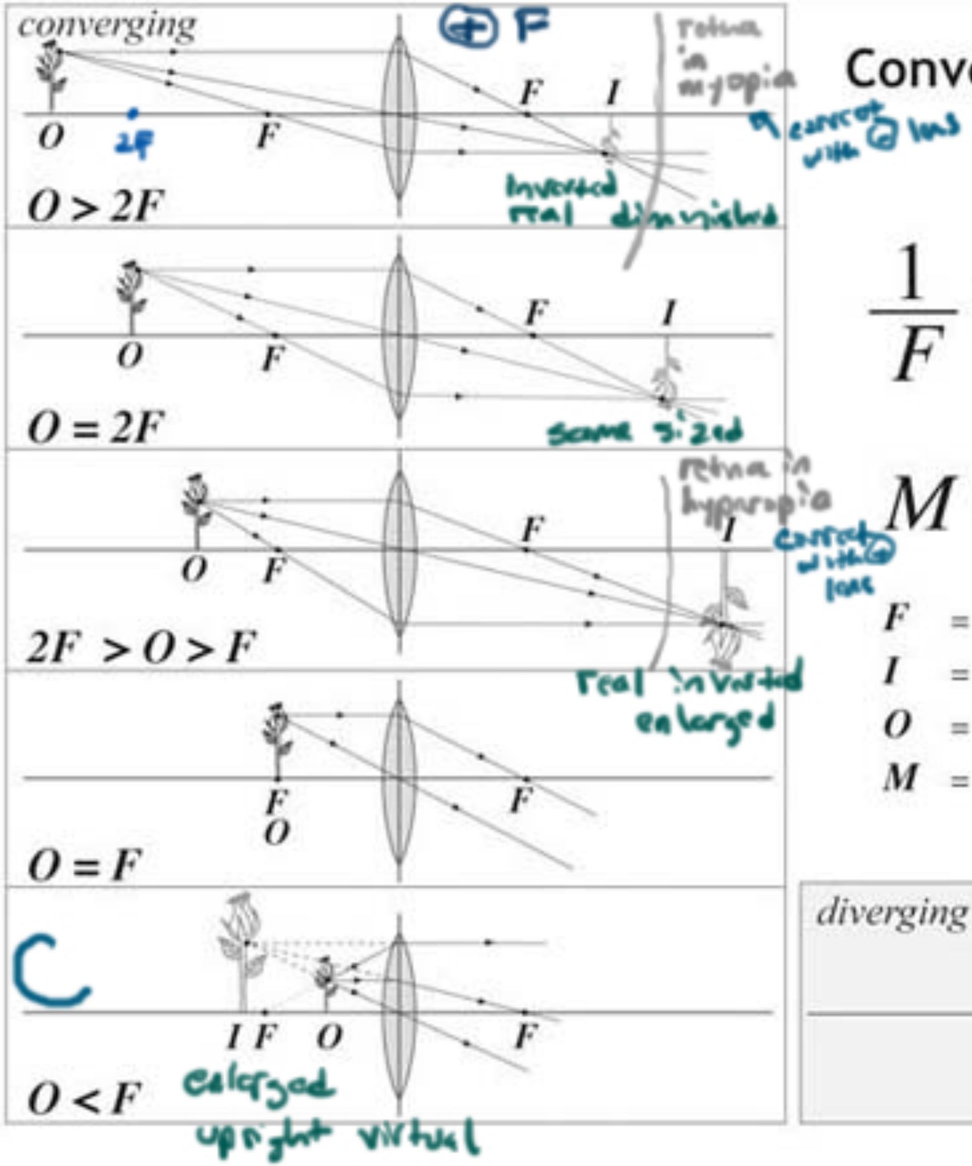
$F_{eye} = 1.5\ cm$

What is power in diopter

F .015 m

$D = \frac{1}{.015} \sim 65$

Converging and Diverging Lenses



$$\frac{1}{F} = \frac{1}{I} + \frac{1}{O}$$

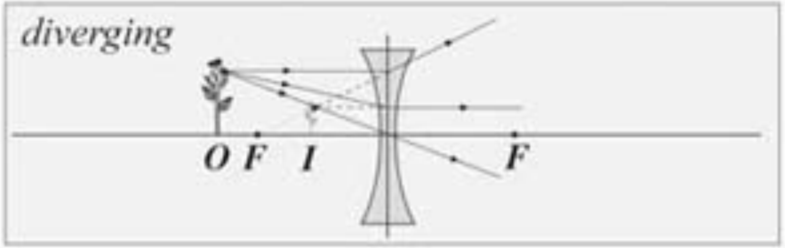
$$M = \frac{-I}{O}$$

F = focal length

I = image distance

O = object distance

M = lateral magnification



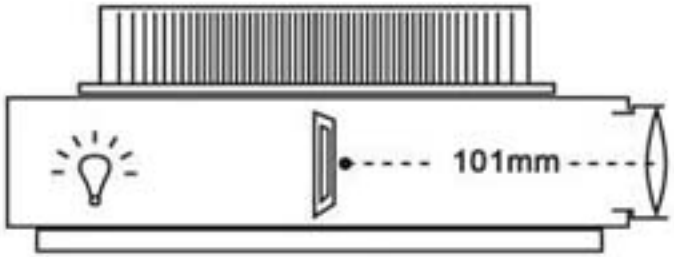
A slide projector has a 100mm projection lens. When the focus knob is adjusted so that the distance between the slide and the lens is 101mm, the projector creates a focused image on a screen 10m in front of the projector. What is the magnification of the image?

F = 0.1 m

O = .101 m

I = 10 m

$M = \frac{-I}{O}$



Slide Projector

a. −99

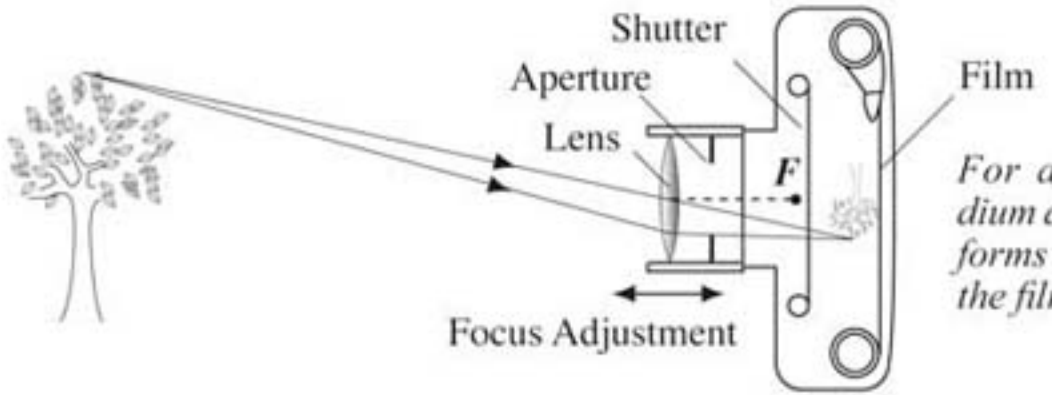
b. 99

c. 100

d. 990

The first prototype of a new camera design can't produce a focused image of an object near the camera. Which of the following might improve the focusing on near objects?

This camera has hyperopia



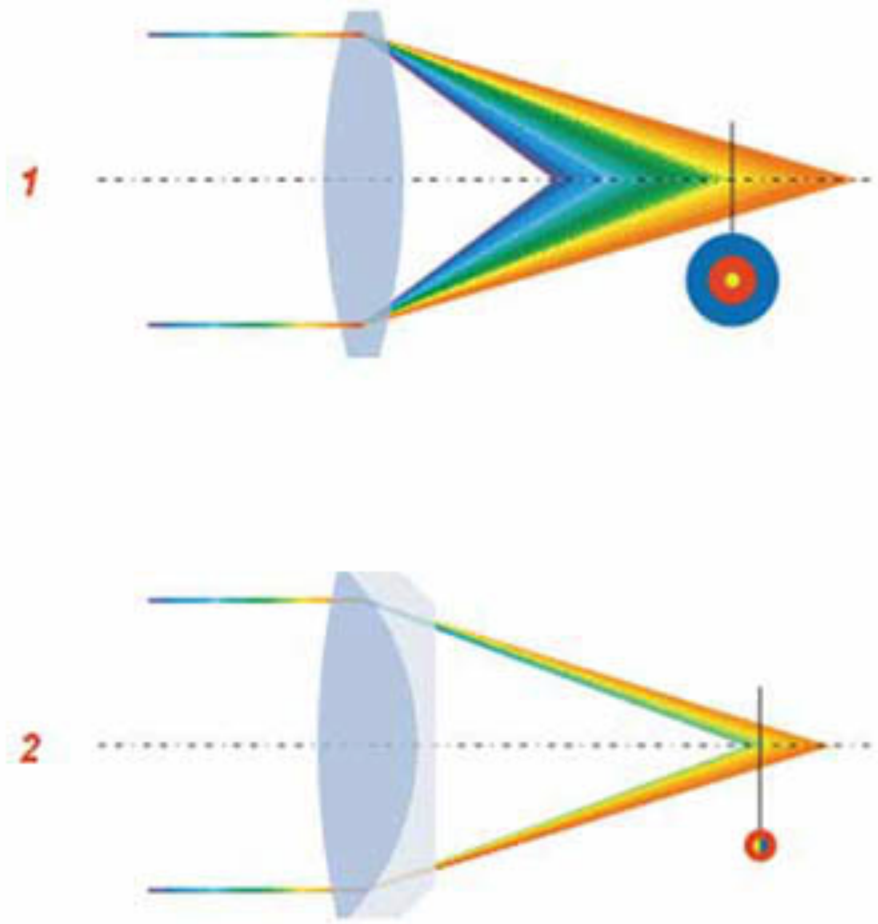
For an object at a medium distance, the camera forms a focused image on the film.

a. decrease the maximum distance between lens and film

b. substitute a lens with increased index of refraction material

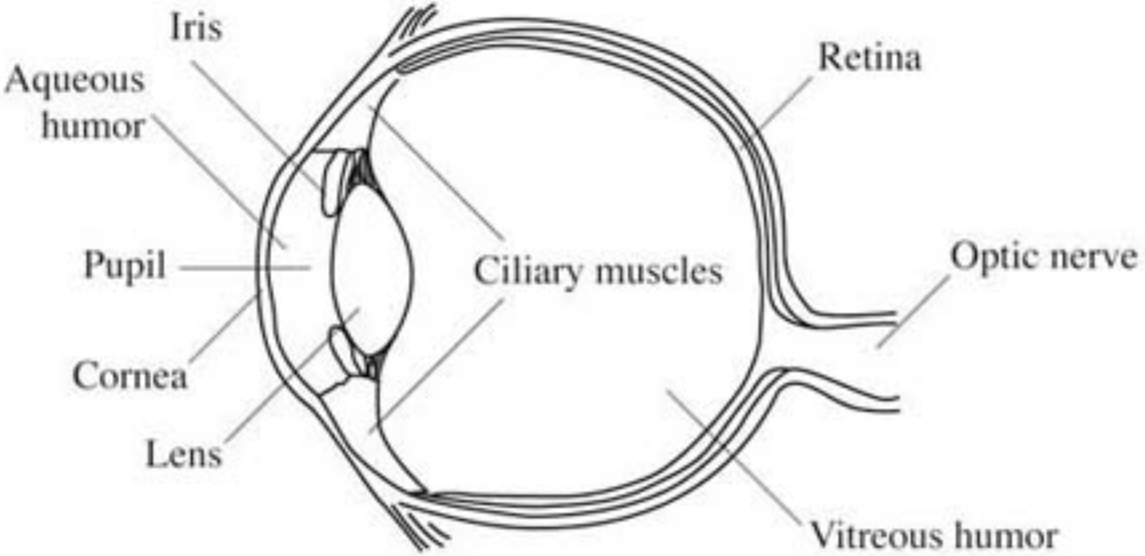
c. increase the radii of curvature of the two lens surfaces

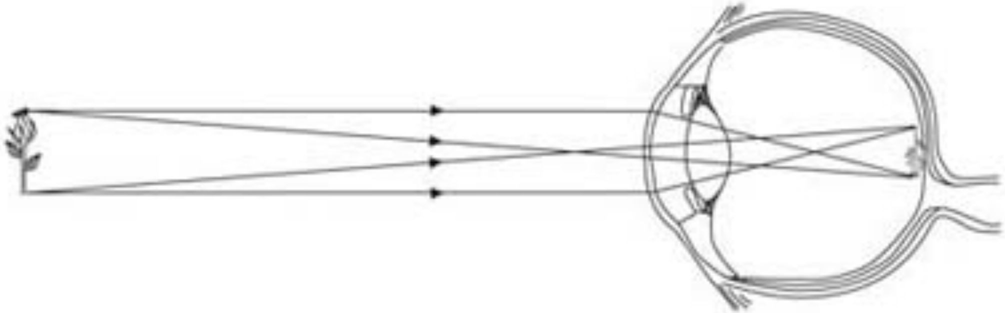
d. decrease the aperture



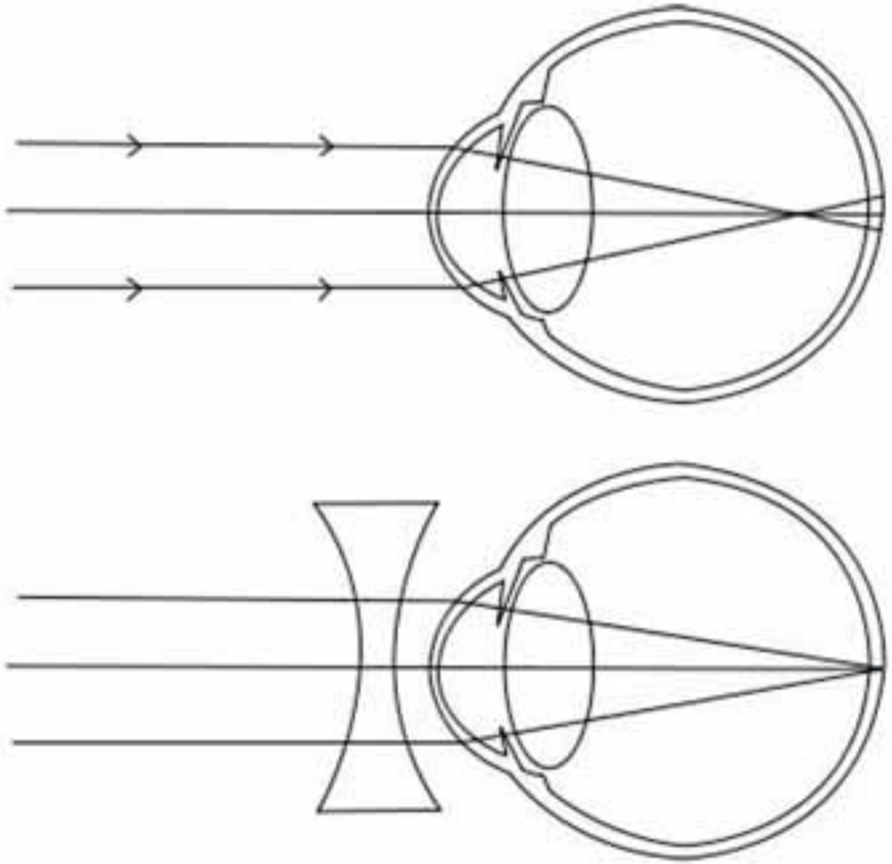
Disparsion causes chromatic aberration

The Human Eye

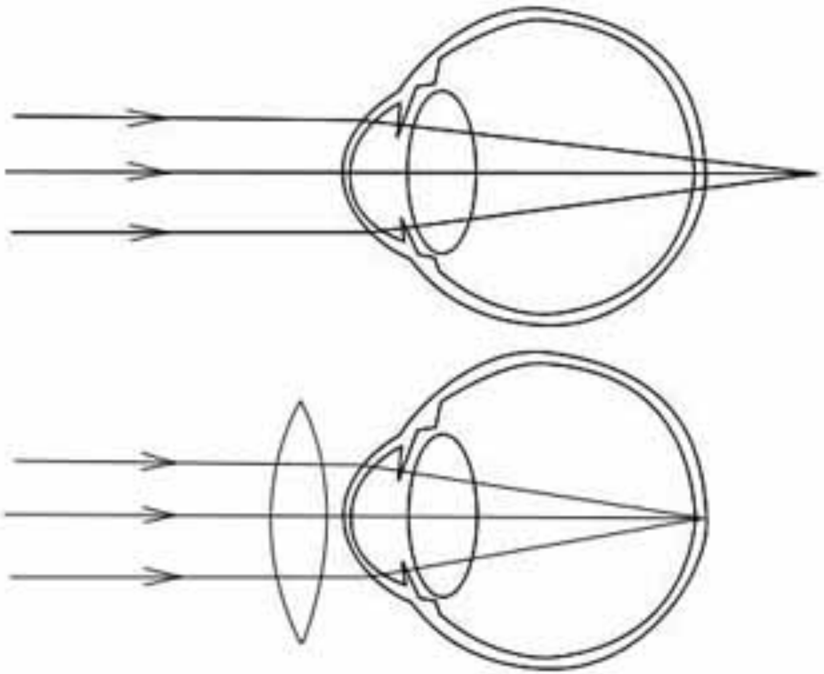




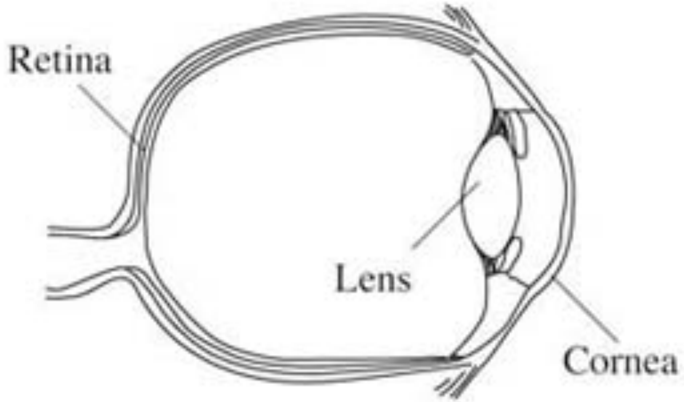
Myopia



Hypropia



A common vision defect results if the eyeball is too long in relation to lens and corneal structure. Which of the following describes the underlying optical causes of poor vision in such cases?



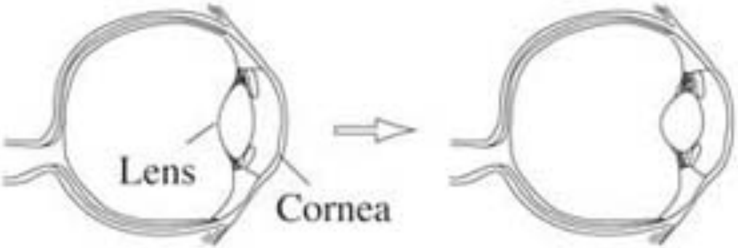
a. An inverted (upside-down) image forms on the retina.

b. Distant objects are focused on the retina, but near objects are focused behind it.

c. The images of far objects focus in front of the retina.

d. The images of near objects focus in front of the retina.

Although most of the diffraction of light entering the eye happens at the air-cornea boundary, adjustments of focal length to distance are made by changes in lens shape, a process called accommodation.



Which of the following happens when the lens becomes less elastic with age and less able to assume a rounded shape?

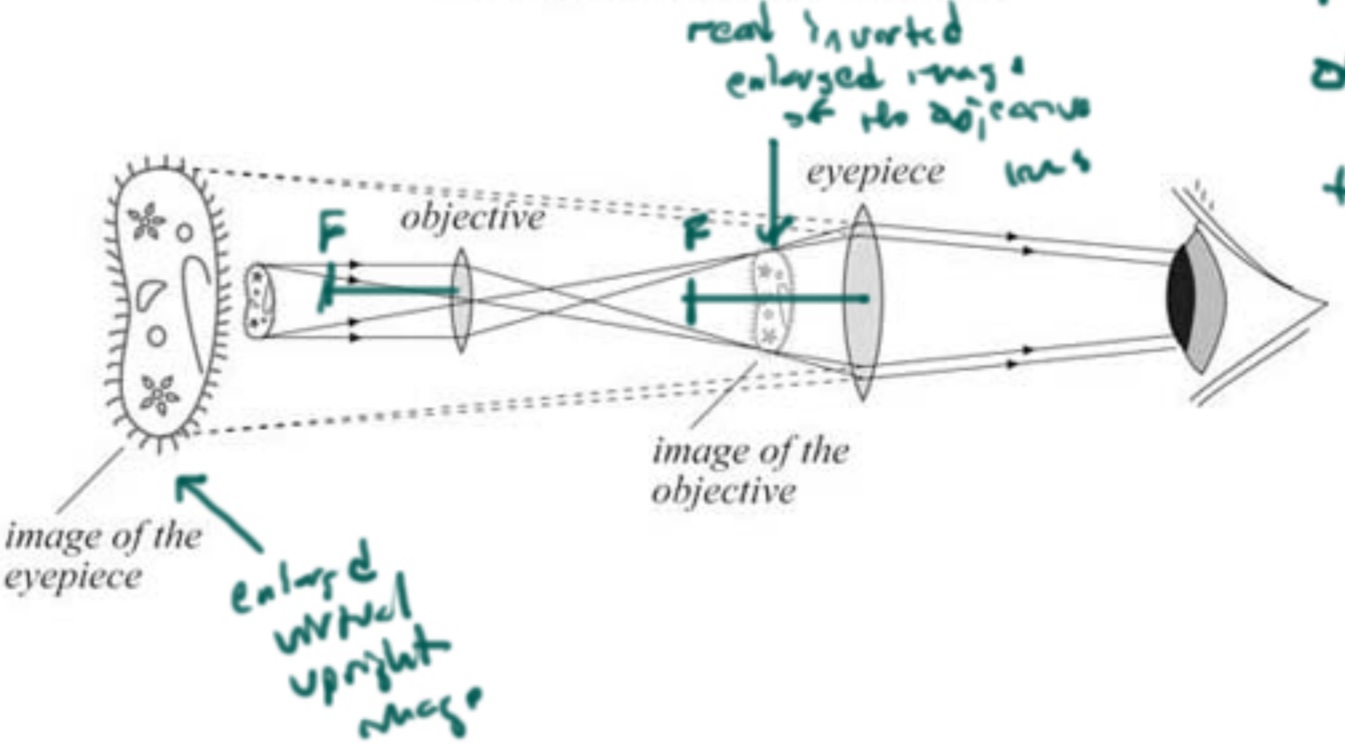
a. The images of near objects focus on the retina.

b. The images of near objects focus in front of the retina.

c. The images of distant objects focus in front of the retina.

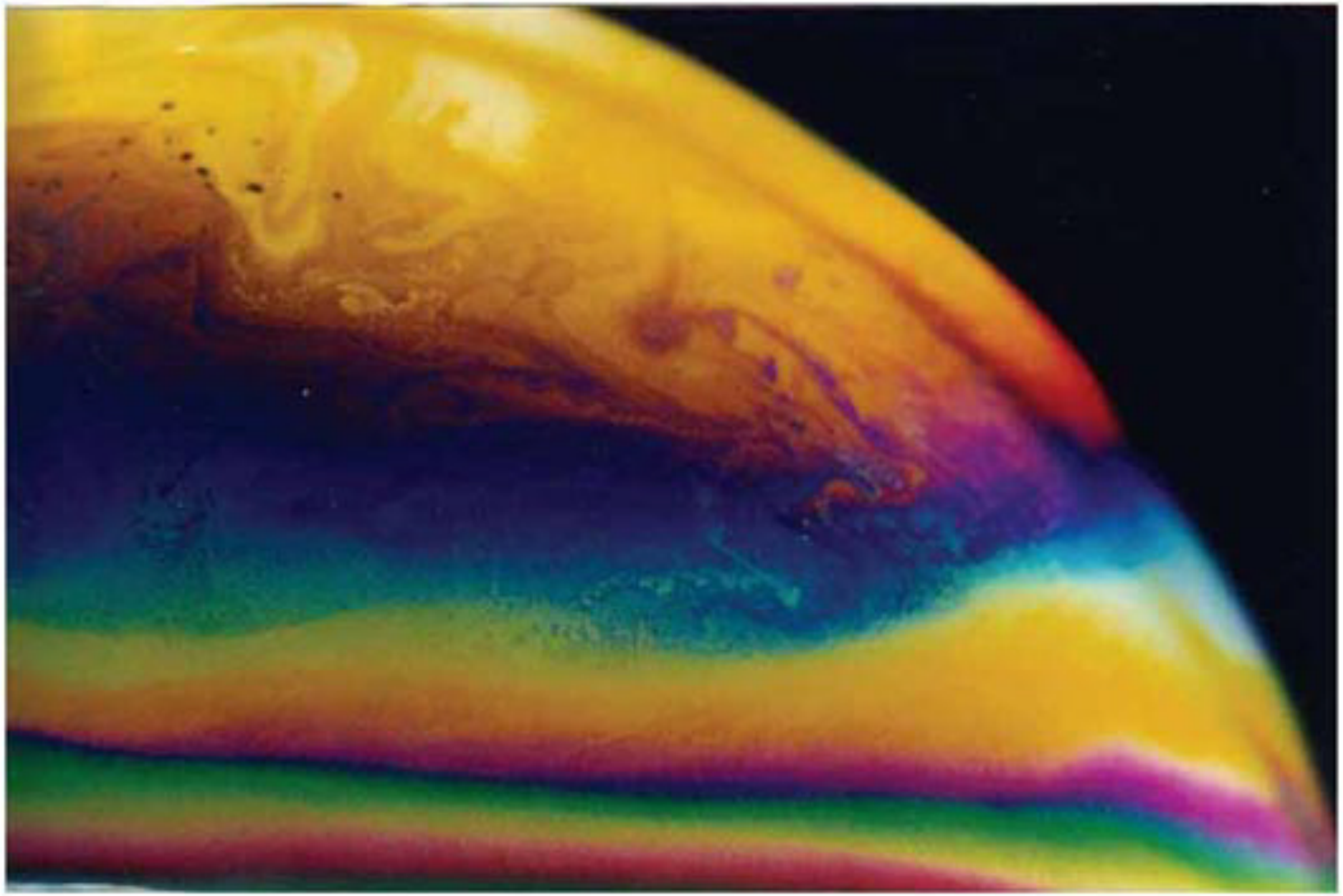
d. The value of the near point increases.

Compound Microscope

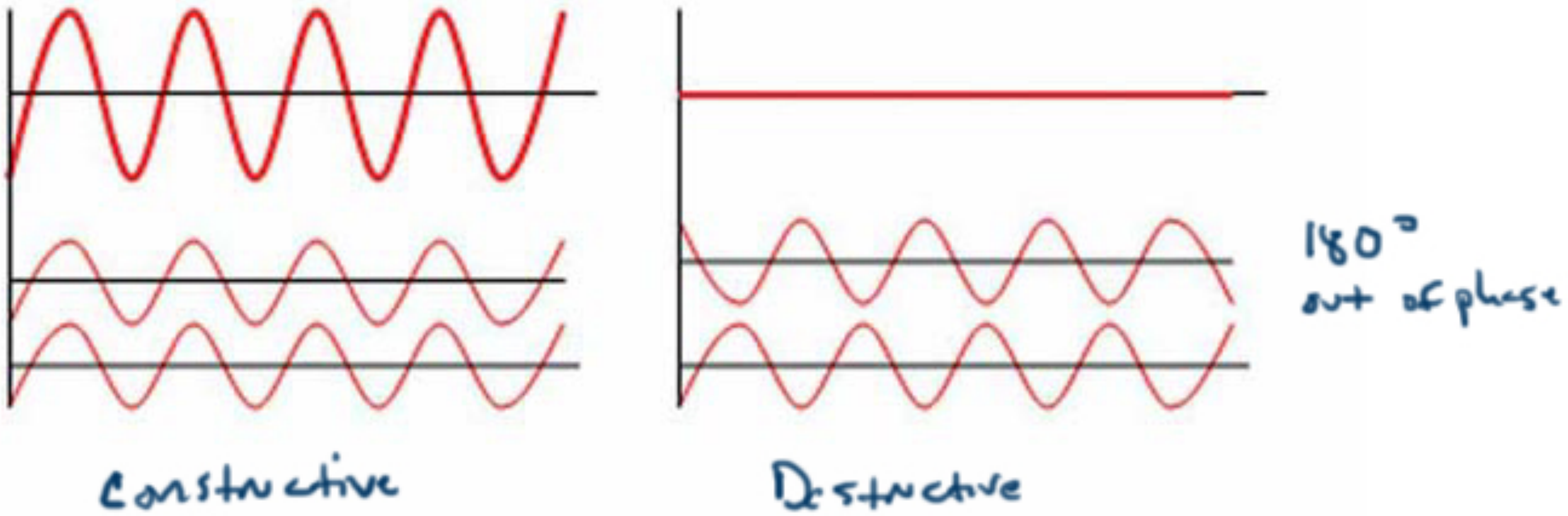


Take the image of the 1st as the object of the 2nd.

Wave
optics



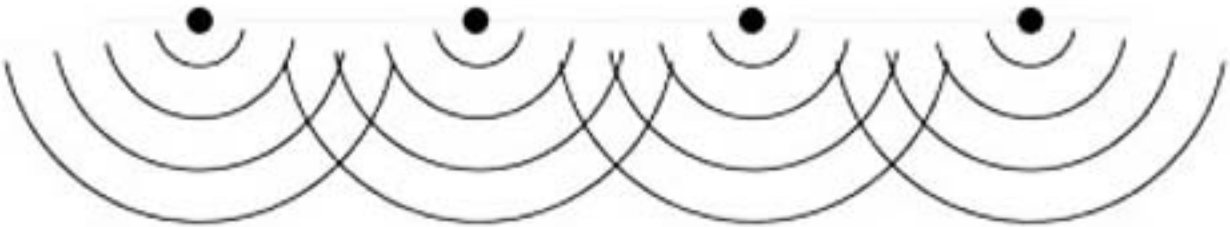
Interference

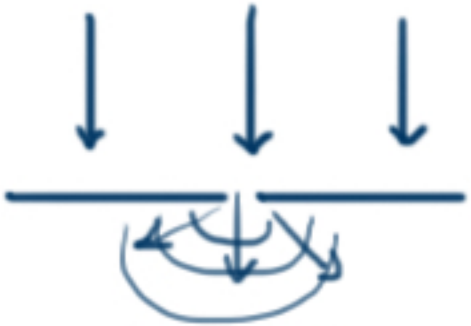


Huygens Principle

Why the ray approach isn't sufficient

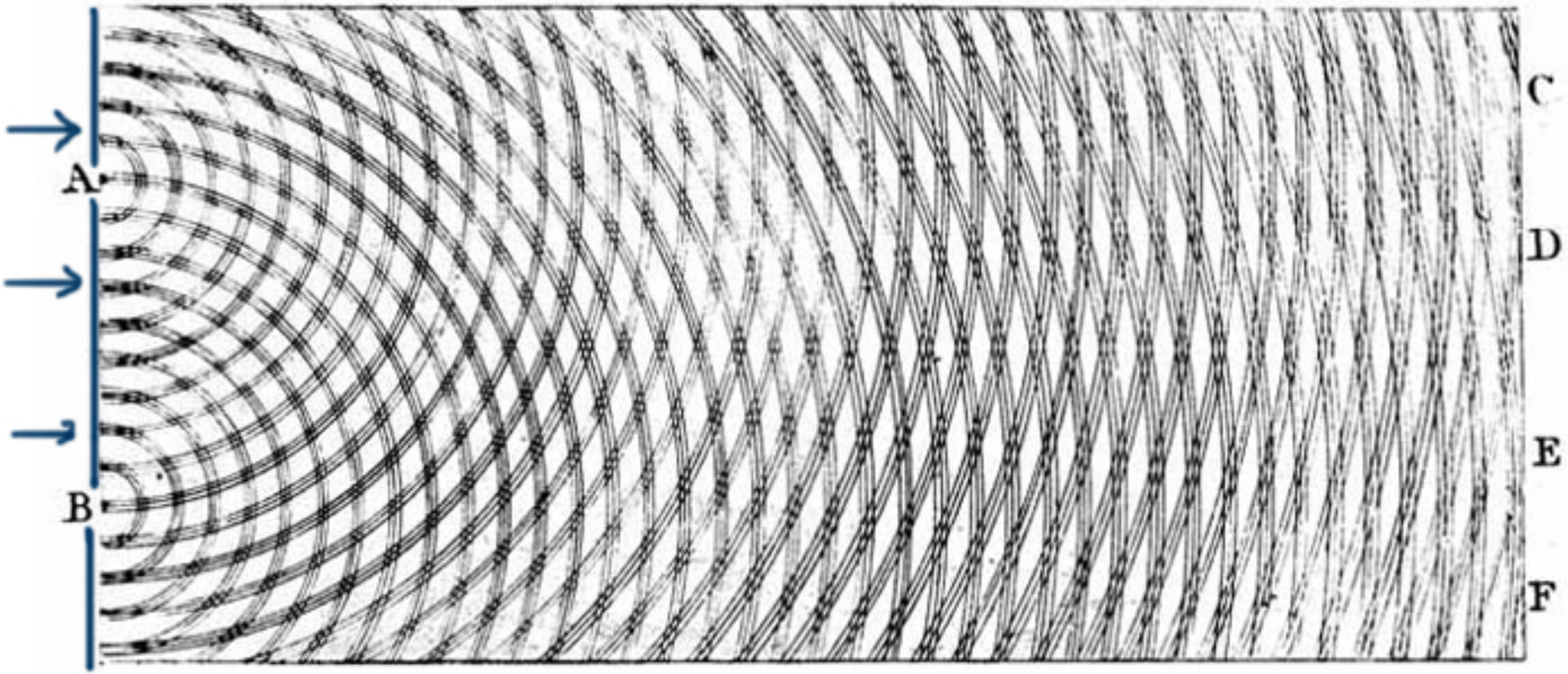
treat the wave front as a multitude of independent sources of wavelets



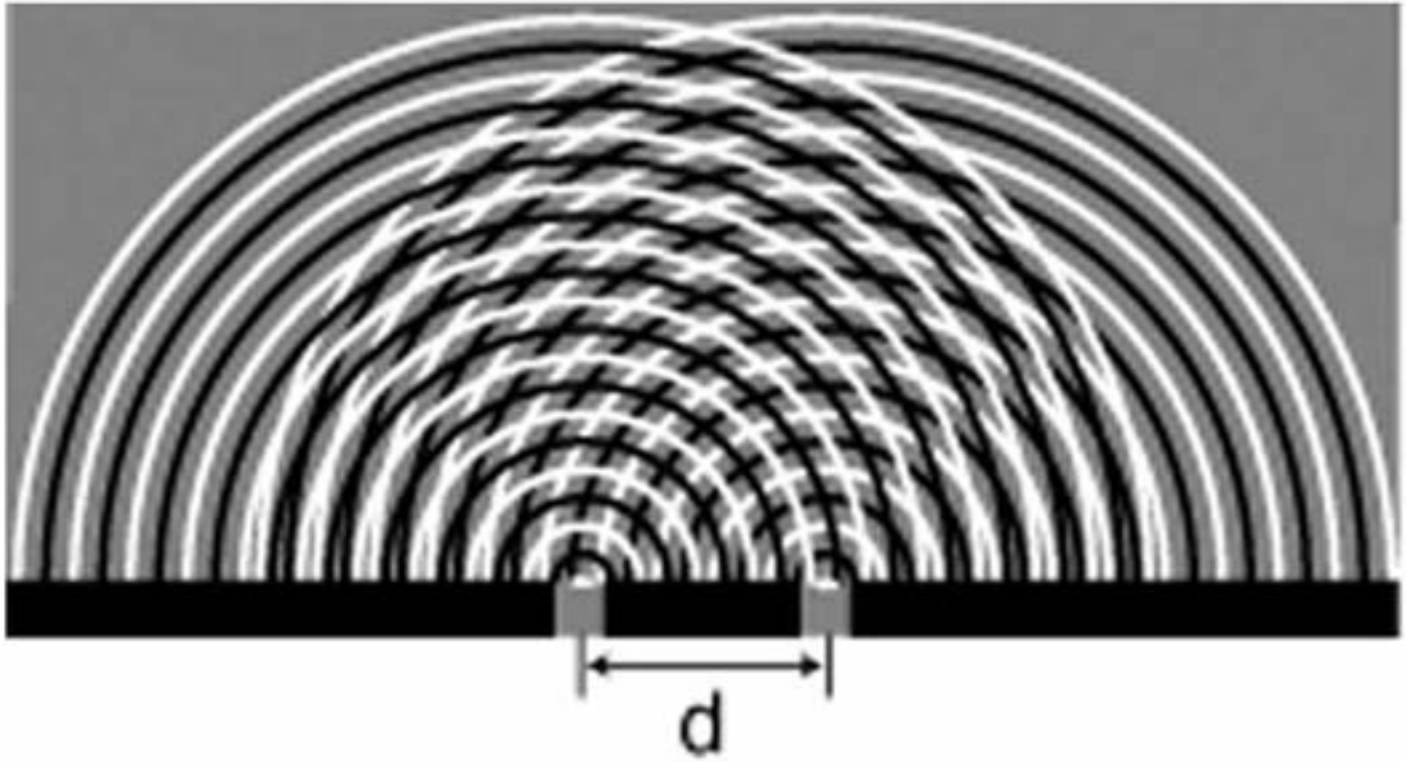


diffraction

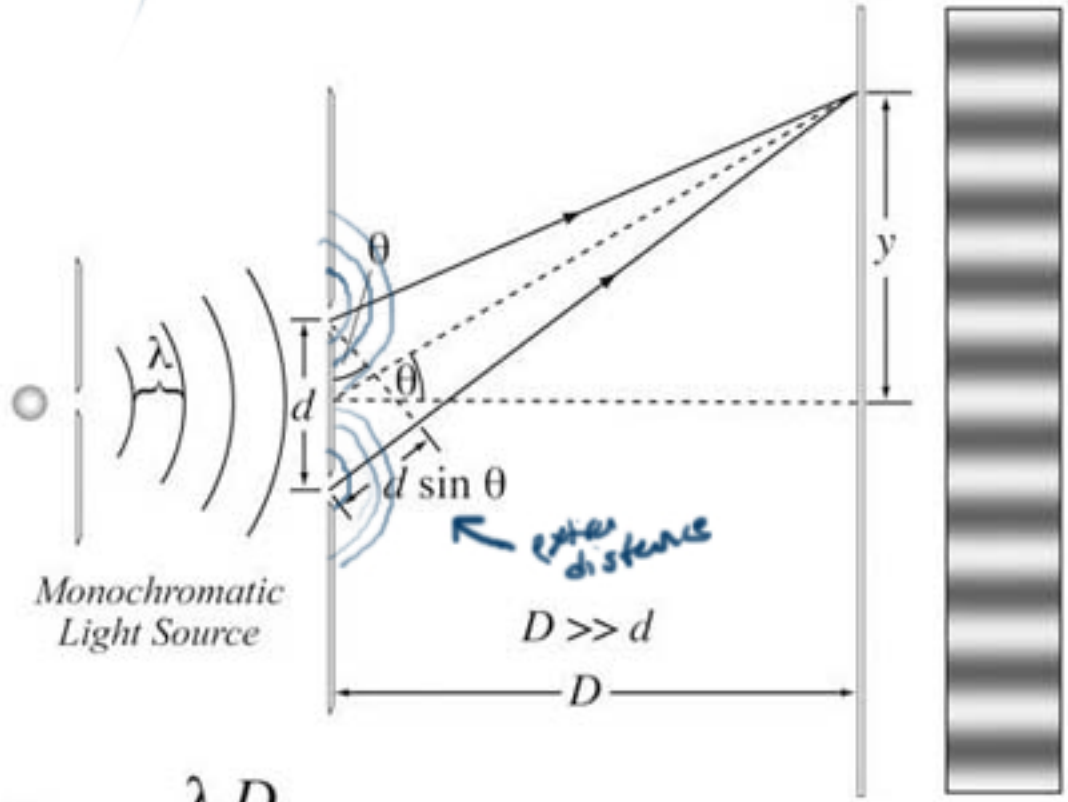
the light bends around the corners - **diffraction**



A
B
C
D
E
F


d

Young's Double Slit Interference



$$d \sin\theta = m\lambda$$

$(m = 0, \pm 1, \pm 2, \ldots)$

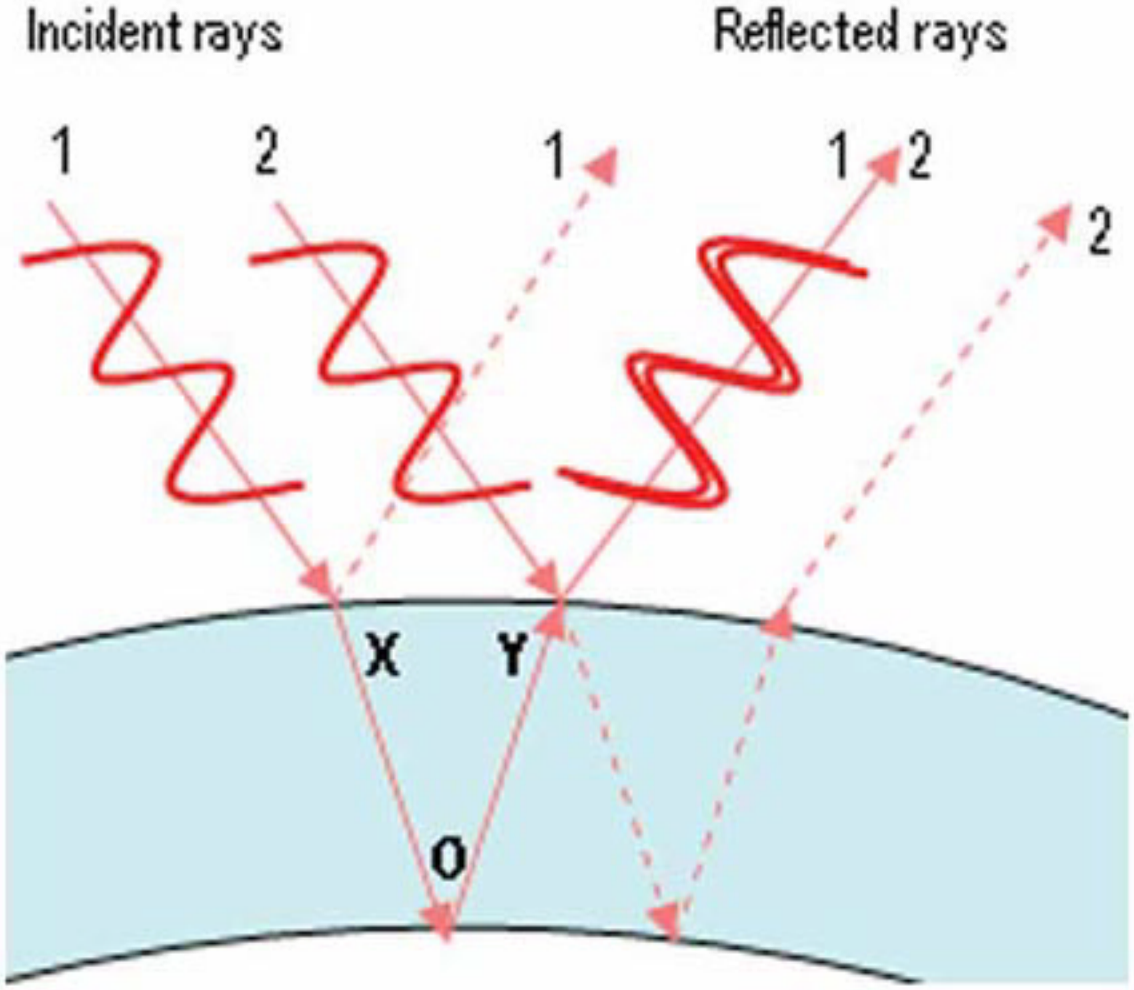
Constructive interference occurs at positions on the screen where the path difference from the two slits is an integral number of wavelengths.

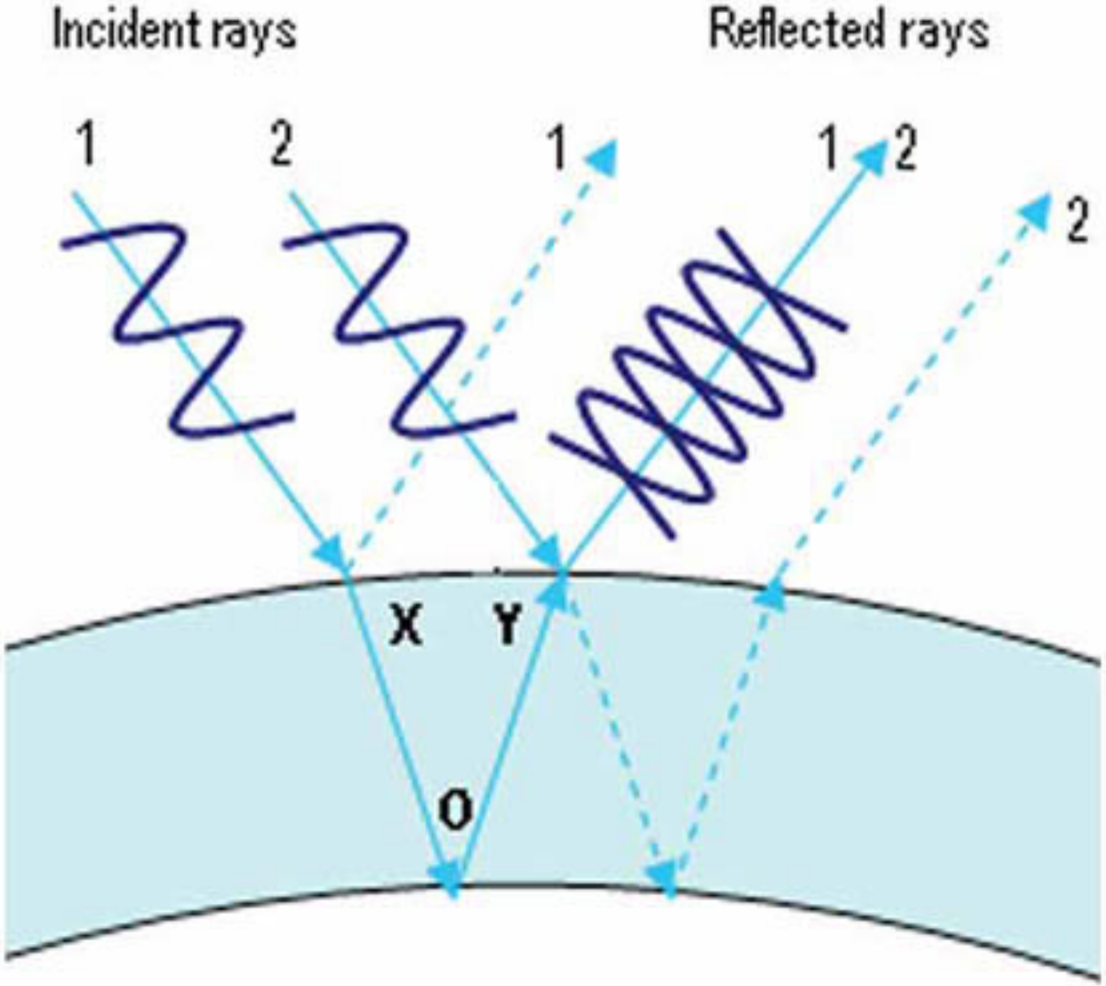
$$y_{\text{br}} = \frac{\lambda D}{d}\, m$$

$(m = 0, \pm 1, \pm 2, \ldots)$

If θ is small, then $\sin\theta \sim y/D$, *and this formula can be applied. Notice that narrowing slit separation, d, causes the fringes to spread out. (A larger angle is required for the same path difference.)*

Thin layer interference




Incident rays
Reflected rays
1
2
1
1
2
2
X
Y
O

Thin Film Interference

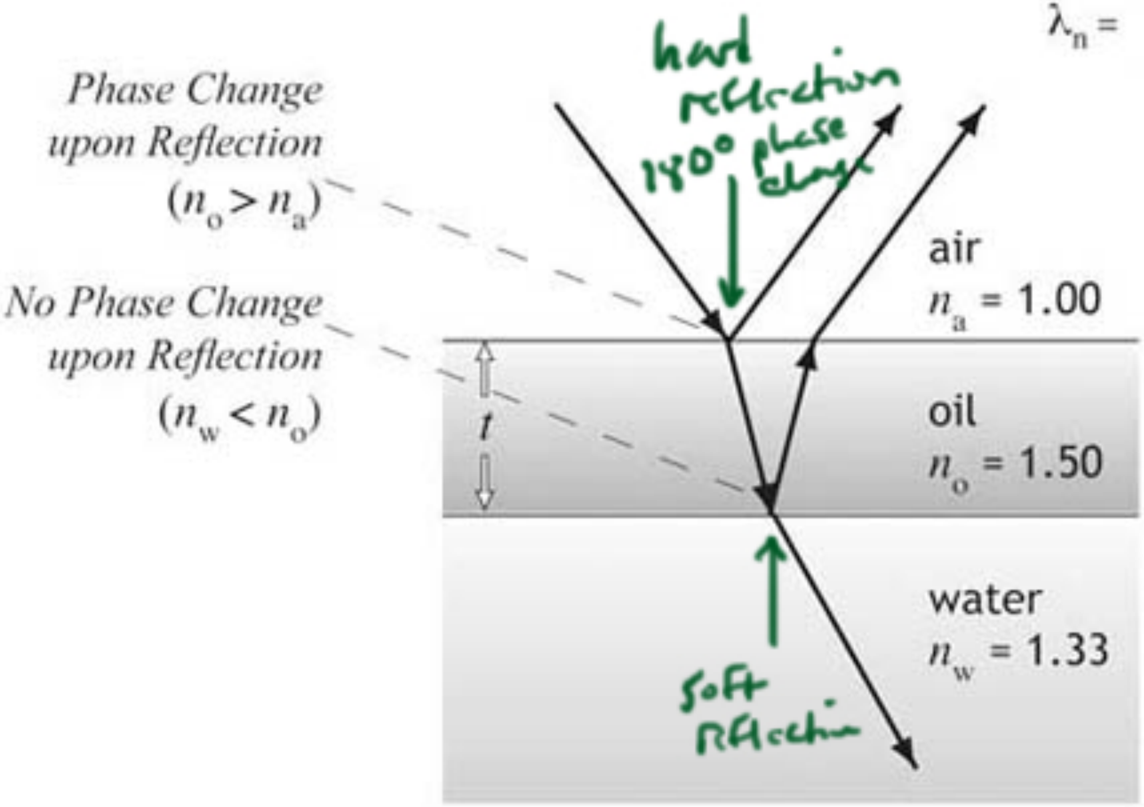
Condition of Constructive Interference
(with one reflection having a phase change)

$$2t = \left(m + \tfrac{1}{2}\right)\lambda_n$$

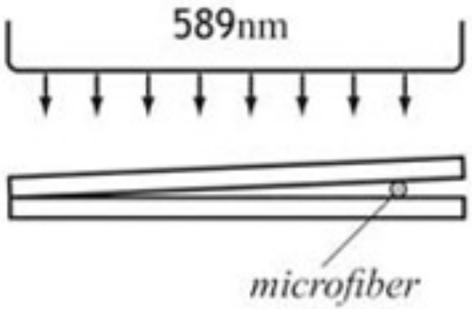
$(m = 0, 1, 2, \ldots)$

because 1 reflection was hard

t = thin film thickness
λ_n = wavelength of light within film medium



An engineer confirmed the thickness of a synthetic microfiber to be approximately 3 microns by placing the filament between two glass slides and illuminating it with a sodium light (λ = 589nm). Which view of the two slides from above shows the pattern of light and dark fringes observed?



a.

b.

c.

d.

$3\mu = 3 \times 10^{-6}$ m

$\lambda = 6 \times 10^{-7}$ m

near microfiber

$2t \sim 10\lambda$

The Michelson Interferometer

to measure very small distances

Imagine we start central fringe is bright.

Move M_1 inward

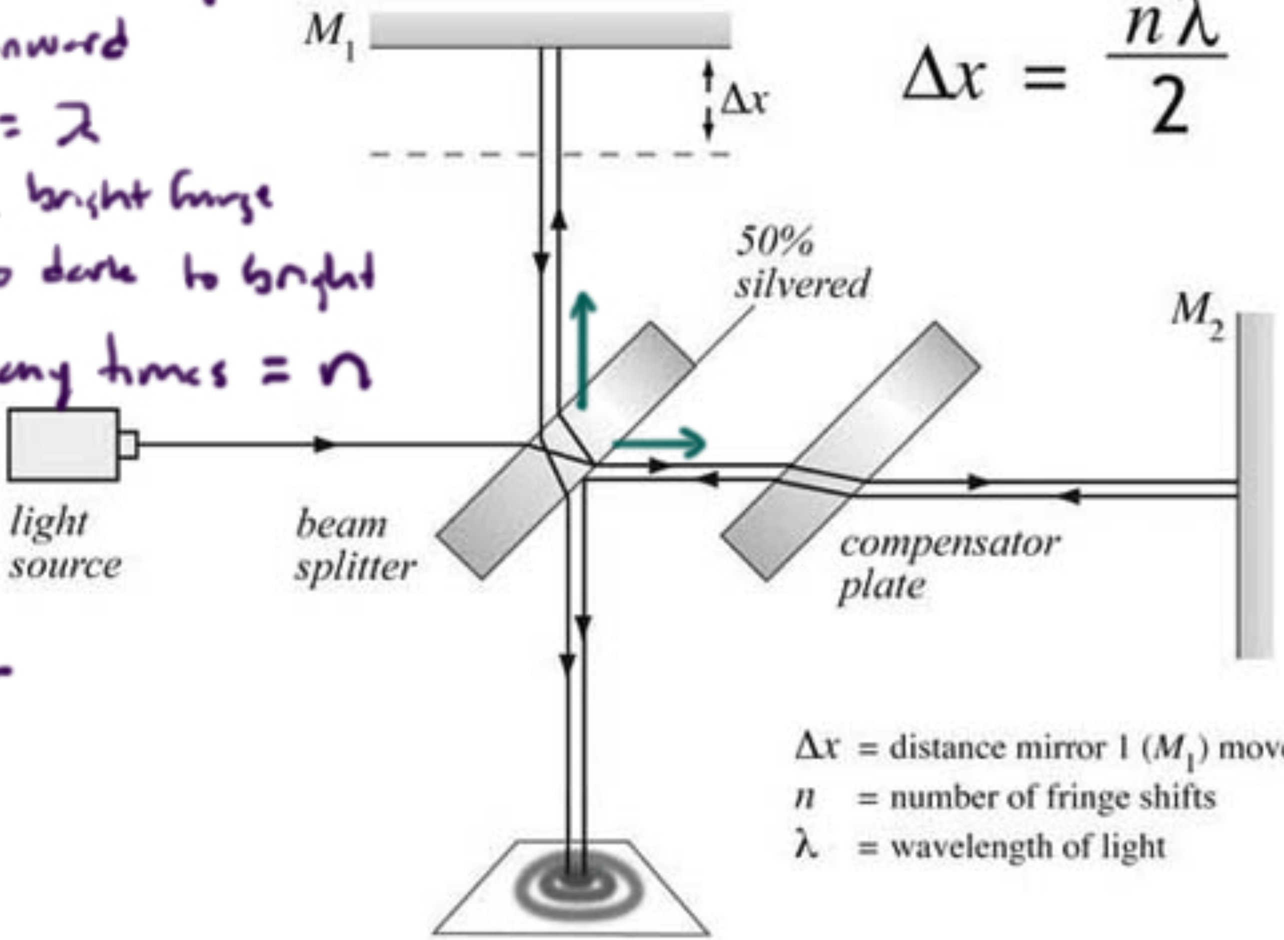
when $2\Delta x = \lambda$

Will see the bright fringe go bright to dark to bright

Count how many times $= n$

$$2\Delta x = n\lambda$$

$$\Delta x = \frac{n\lambda}{2}$$

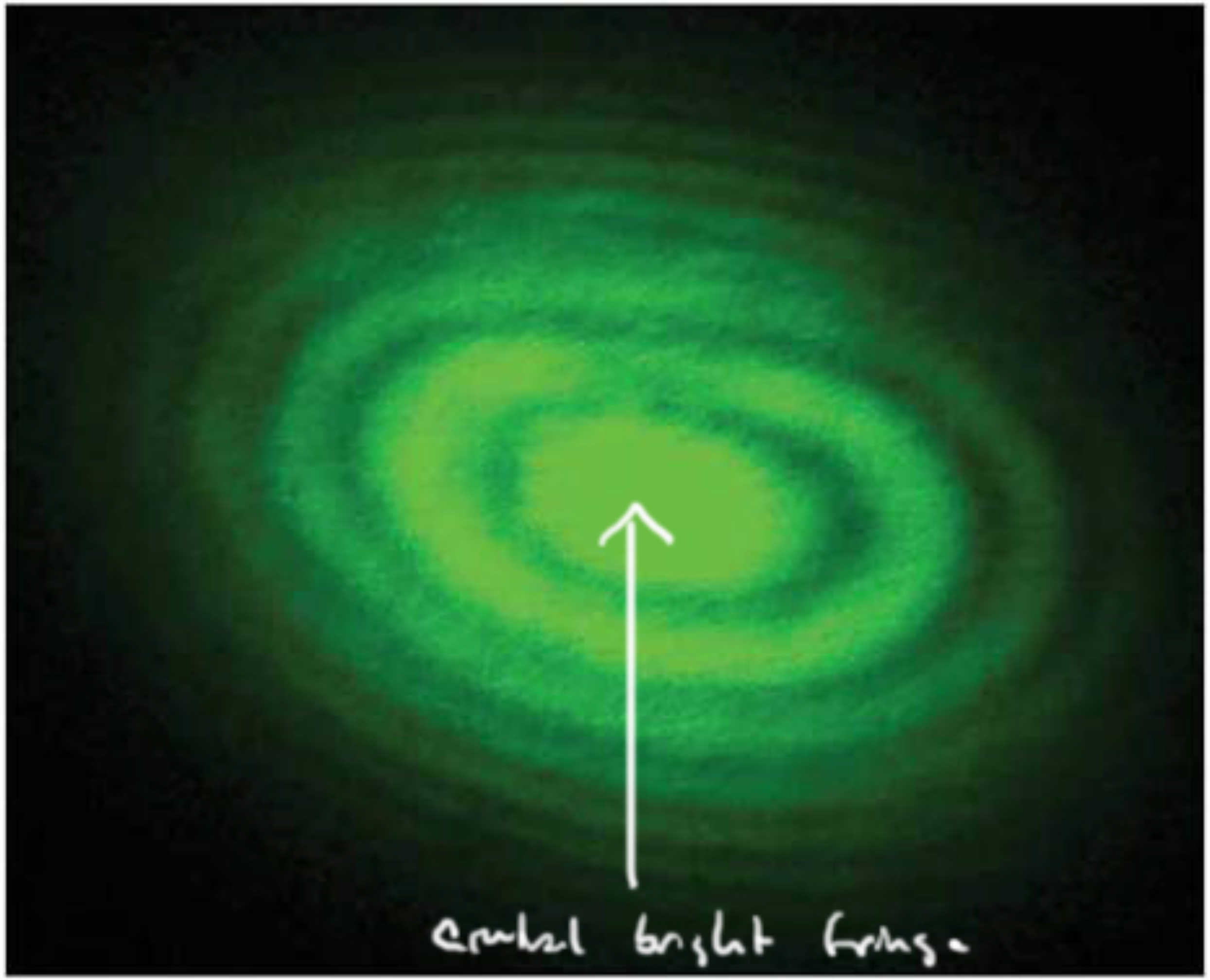


$$\Delta x = \frac{n\lambda}{2}$$

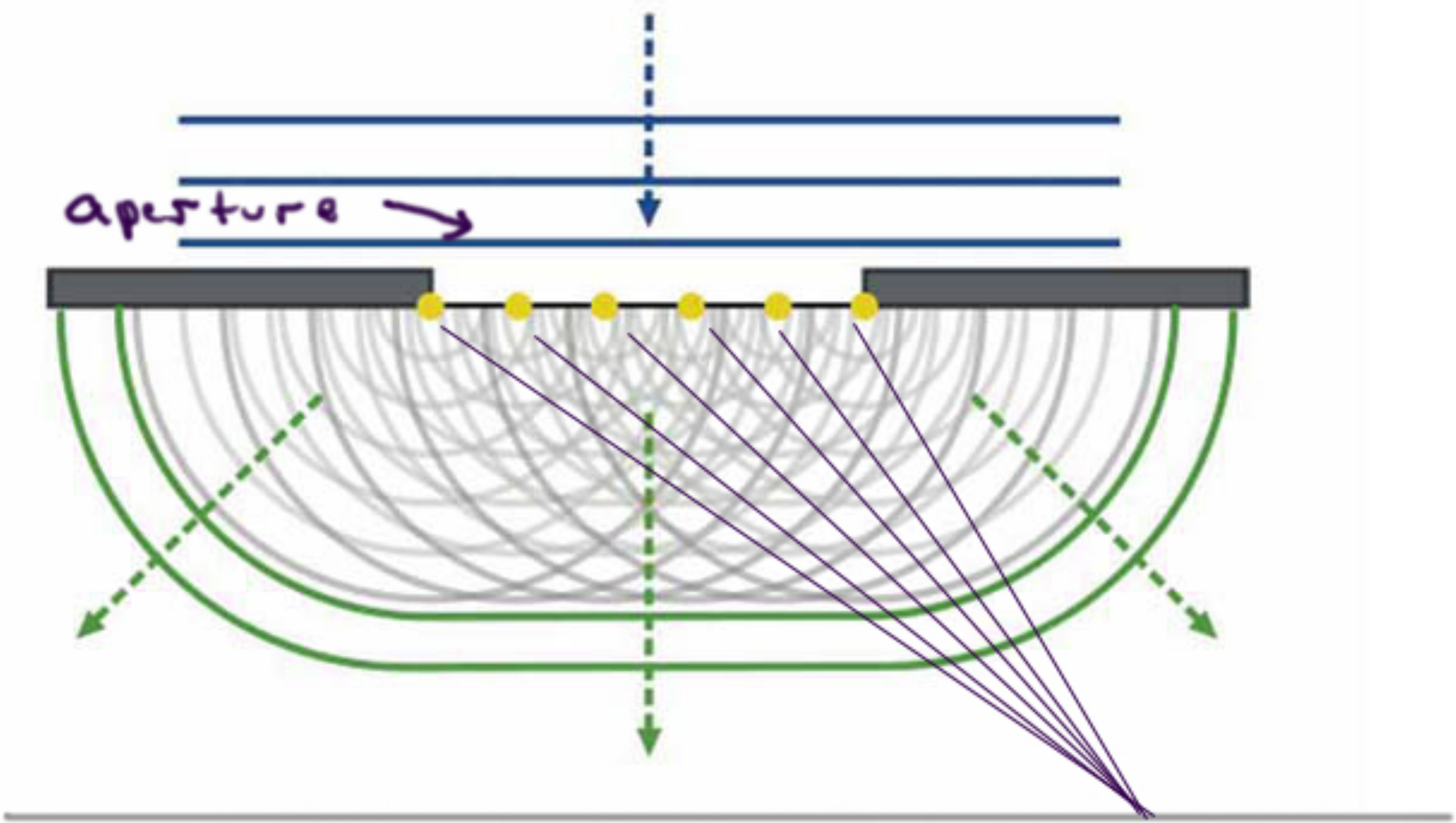
Δx = distance mirror 1 (M_1) moved

n = number of fringe shifts

λ = wavelength of light

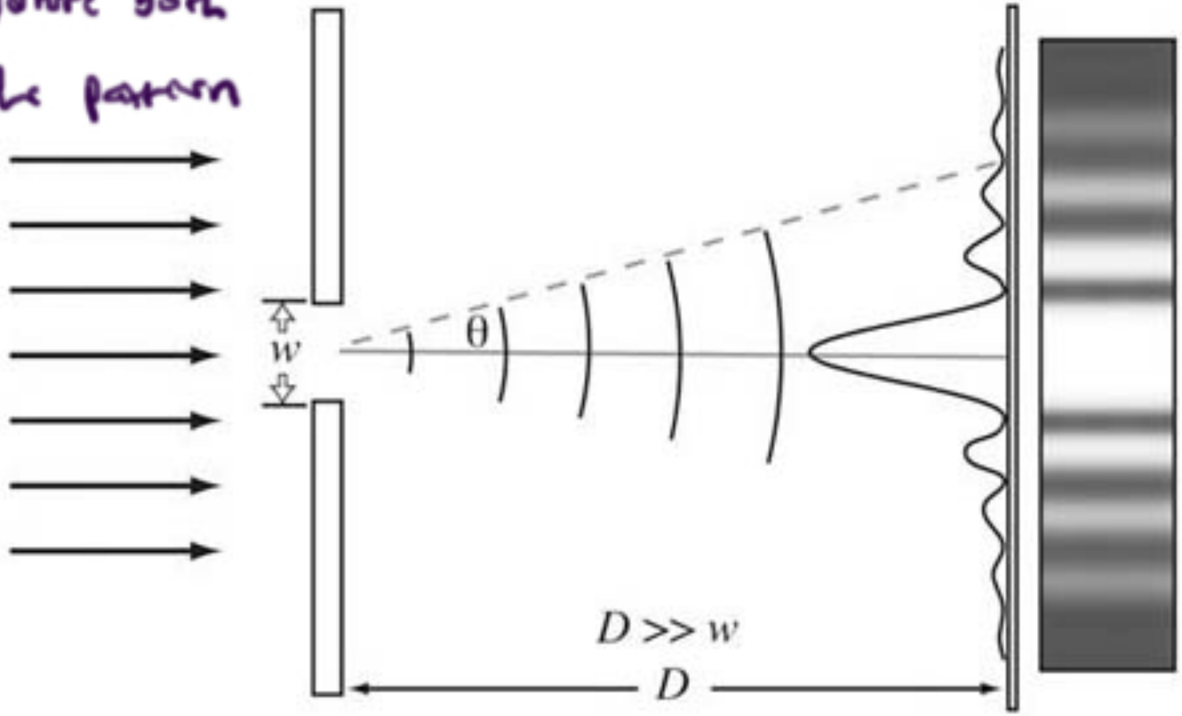

central bright fringe.

Single Slit Diffraction



Single Slit Diffraction

shorter λ
or bigger aperture both
compress the pattern

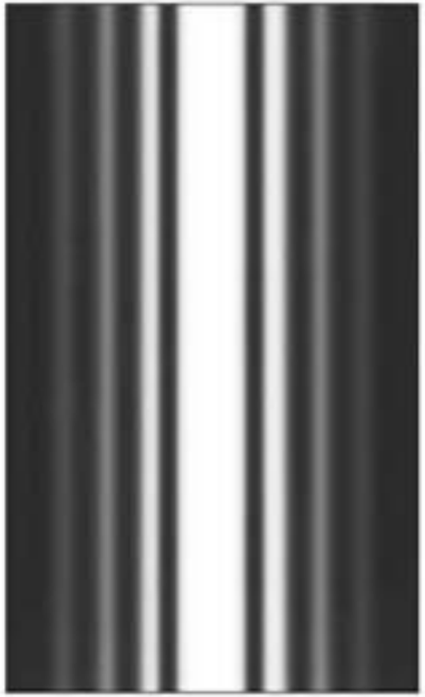


$$\sin\theta = \frac{n\lambda}{w}$$

$(n = \pm 1, \pm 2, \ldots)$

angular positions of dark fringes (intensity minima)

Monochromatic light is incident on a screen which is provided with a narrow 200μ wide slit. The light emerging from this slit casts the visible pattern seen at right onto a second screen $1.5\mathrm{m}$ beyond the first slit. The width of the central bright fringe is $10\mathrm{mm}$. Which of the following actions would *increase* the width of this central fringe?



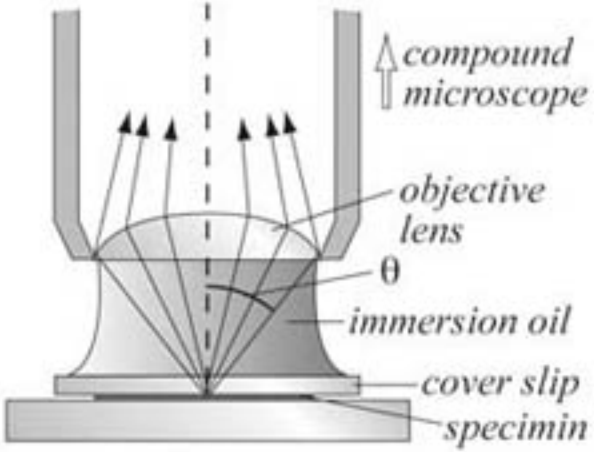
a. Decreasing the wavelength of the light

b. Narrowing the slit to 100μ in width

c. Moving the second screen to $1.0\mathrm{m}$ distance from the first screen

d. Employing an incandescent light source

The resolution of a microscope reflects the ability of the apparatus to form an image in which fine details can be discriminated. A key to resolving power is the *numerical aperture* of the objective lens, $n \sin(\theta)$ (n is the refractive index of the medium between the specimin and lens. The angle θ is shown at right.)



higher n
lower v
same f
shorter λ

Immersion oil with refractive index matched to glass, 1.51, is often used to fill the space between cover slip and objective lens. What is the most important contribution of immersion oil to microscope resolution?

a. eliminating chromatic aberration

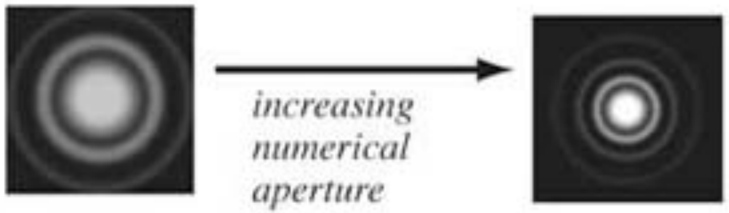
b. preventing variation of cover slip thickness

c. reducing spherical aberration by making the media homogeneous

d. increasing the possible phase difference at an image point of light waves originating from the same object point

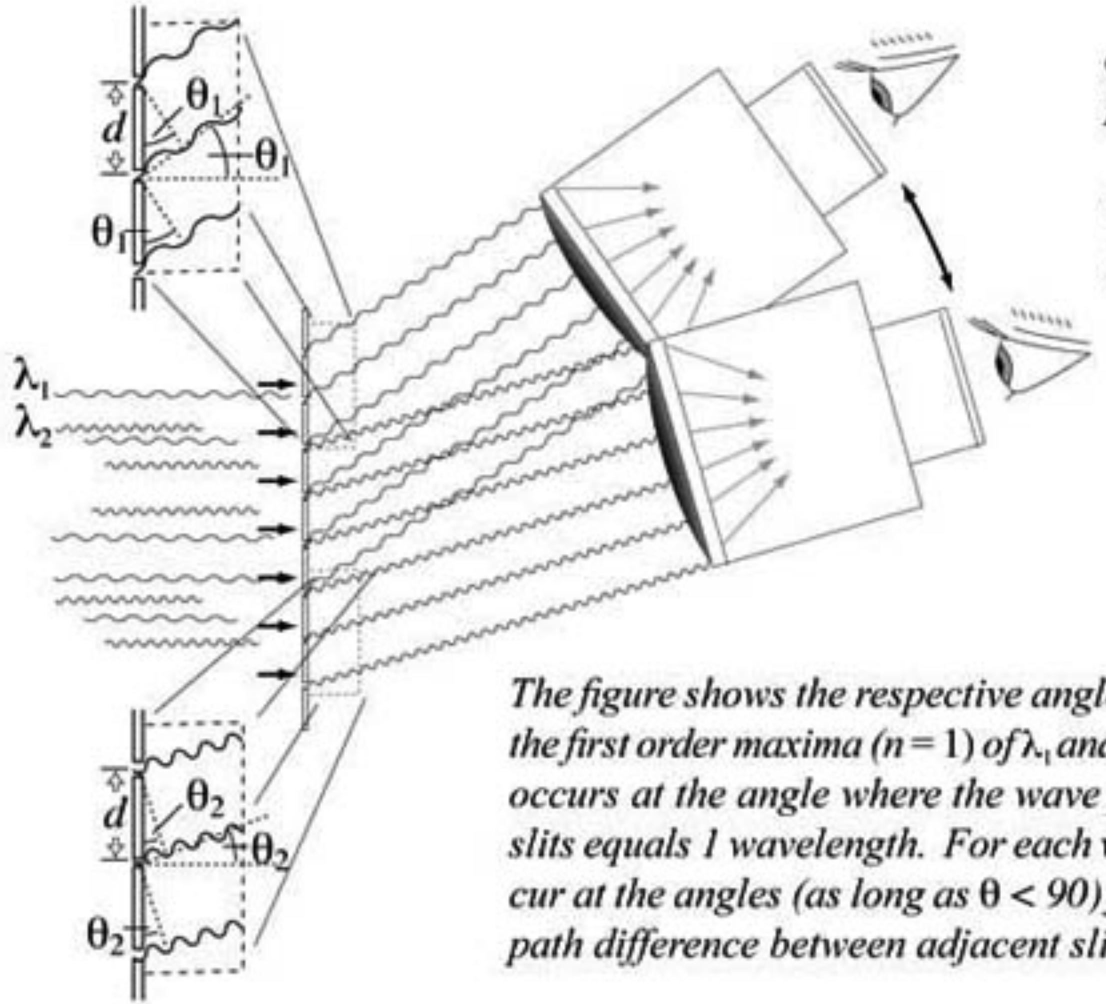
The answer is (d)

Diffraction of light passing through a circular aperture produces an interference pattern similar to single slit diffraction. By *Hugen's principle*, each portion of the aperture acts as a source of waves. For a given image point, the interference of wavelets yields a diffraction pattern known as an *airy disk*. Widening the slit narrows the central maximum in single slit diffraction. Likewise, widening a circular aperture increases the phase difference possible for different light paths, increasing the number of diffraction orders captured, which decreases the size of the central maxima of the airy disk image of a given point source. (With its increased index of refraction, the wavelength of light is shortened in oil vs. air, which has the same effect as widening the aperture, increasing the number of diffraction orders captured.)



When the central maximum of one airy disk falls on the first minimum of another (Rayleigh's criterion), the images are said to be just resolved, so decreasing the size of central maxima increases the ability to resolve two airy disk patterns.

The Diffraction Grating Spectrometer



Condition for Maxima for a Particular Wavelength:

$$d \sin \theta = m\lambda$$

$(m = 0, 1, 2, 3, \ldots)$

just like double slit interference

The figure shows the respective angles of deviation (θ_1 and θ_2) for the first order maxima ($n = 1$) of λ_1 and λ_2. The first order maximum occurs at the angle where the wave path difference for adjacent slits equals 1 wavelength. For each wavelength, maxima also occur at the angles (as long as $\theta < 90$) for $n = 2, 3$ etc. wavelengths path difference between adjacent slits.

The image above shows the zeroth, first and second spectral orders cast on a screen by the beam of a green argon gas-ion laser (λ = 514.5 nm) incident on a diffraction grating. Which pattern results after the entire assembly of laser, grating and screen are immersed in water?

higher n
shorter λ

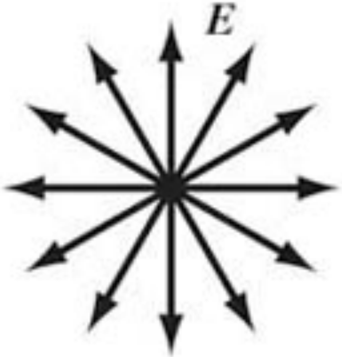
a. 

b. 

c. 

d. 

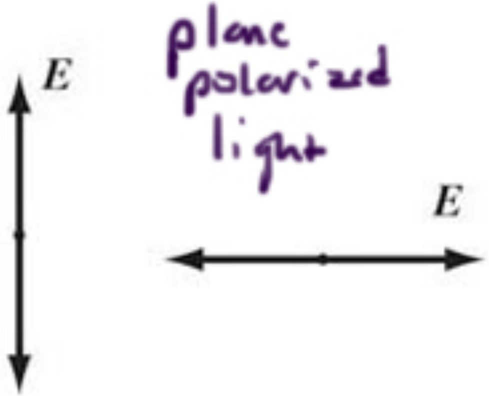
Polarization of Light



Direction of propagation is perpendicular to the page.

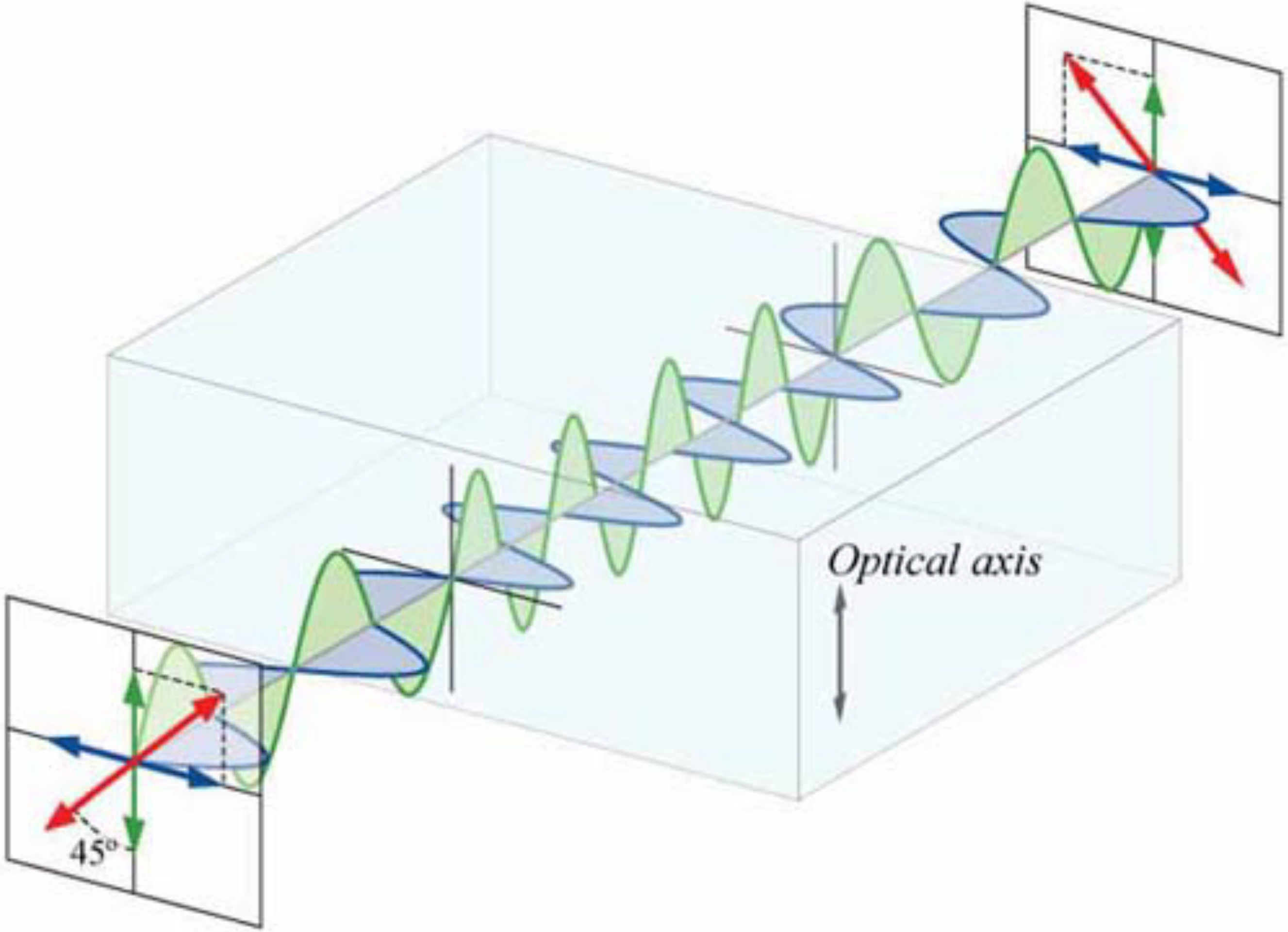
Unpolarized Light

With unpolarized light, all directions of electric field vibrations perpendicular to the direction of wave propagation are possible. Most light sources produce unpolarized light.

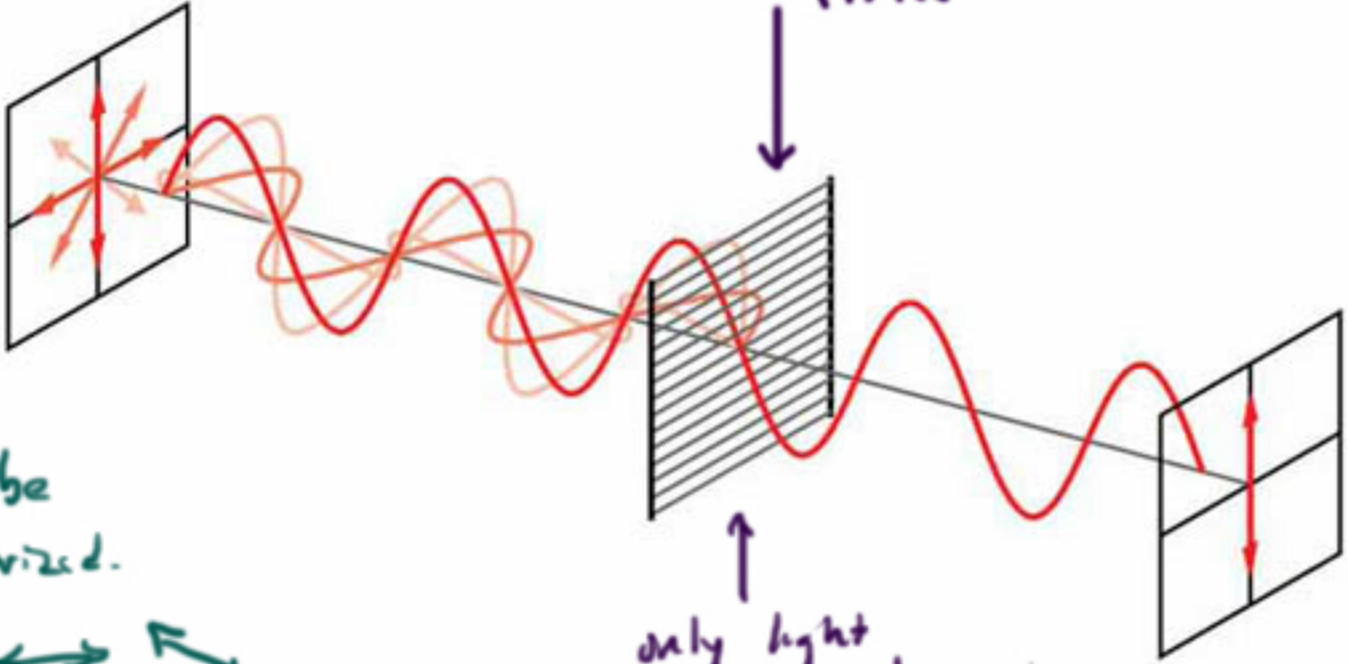


Polarized Light

With plane polarized light, the electric field vibrates in a single plane perpendicular to wave propagation. Different means exist to produce polarized light from an unpolarized source including reflection, selective absorption, double refraction and scattering.



Optical axis
45°



- Light can also be circularly polarized.

used in circular dichroism spectroscopy to assay the degree of order in a protein's 2° structure

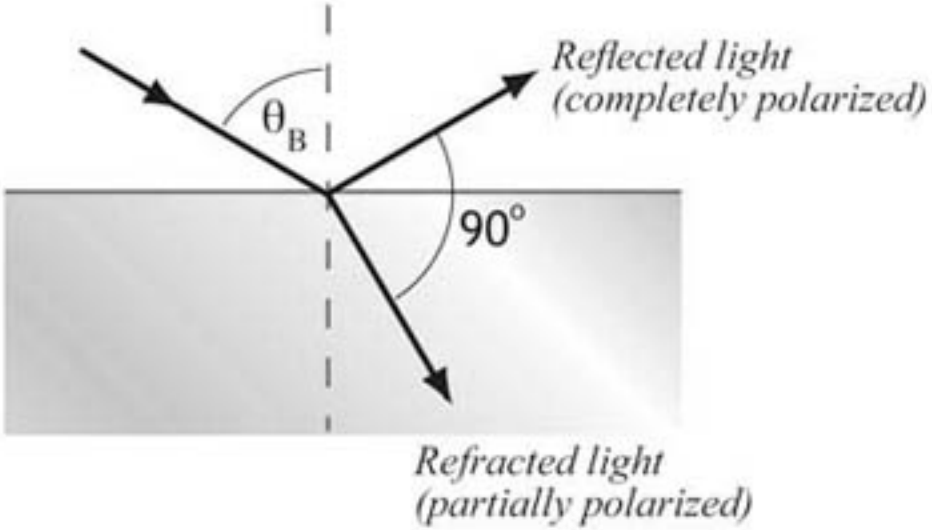
- *Reflection* polarizes light. For intermediate angles of incidence, between 0° and 90°, at least some of the reflected light is polarized because light in which the electric field vibrations parallel to the surface are more strongly reflected.

- *Selective absoprtion* polarize light. A *polaroid film* only allows the components of the electric field vibrations to pass that are parallel to its transmission axis.

- *Double refraction* produces polarized light within *birefringent materials*. In these substances, such as calcite and quartz, the index of refraction is not the same in all directions. Double refraction causes an unpolarized light beam to be split into an *ordinary (O) ray* and an *extraordinary (E) ray*, which are polarized in mutually perpendicular directions.

- *Scattering* produces polarized light. For example, the vibrations of air molecules in the horizontal plane reaches the earth while the vibrations in the vertical plane travel into space.

Brewster's Angle



derived from Snell's Law

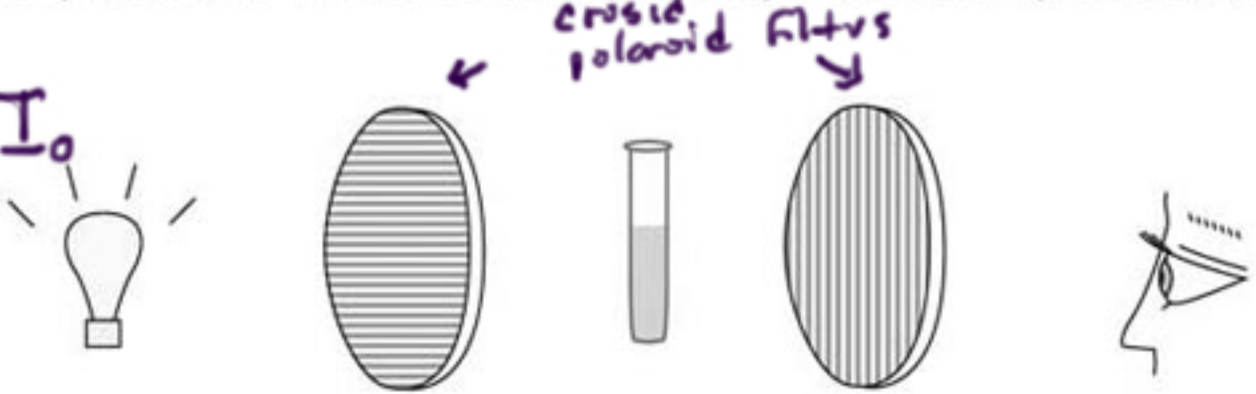
$$\tan\theta_B = \frac{n_2}{n_1} \quad (\text{if } n_1 \sim 1) \quad \tan\theta_B = n_2$$

supplemental

Brewster's angle, at which the reflected light is completely polarized, depends on the indices of refraction of the two media. (Note that the index of refraction of air is very close to 1, so Brewster's Law can often be simplified to $\tan\theta_B = n_2$*).*

Optically active substances possess the ability to rotate the plane of polarization of plane polarized light. To determine whether a transparent substance was optically active, a biochemist placed it between two crossed polarizers, illuminated the assembly as below, and viewed through the 2nd polarizer. Which of the following indicated optical activity?

$I = \cos^2\theta \, I_0$



a. Angular rotation of the image of the substance

b. Greater brightness where light was passing through the substance

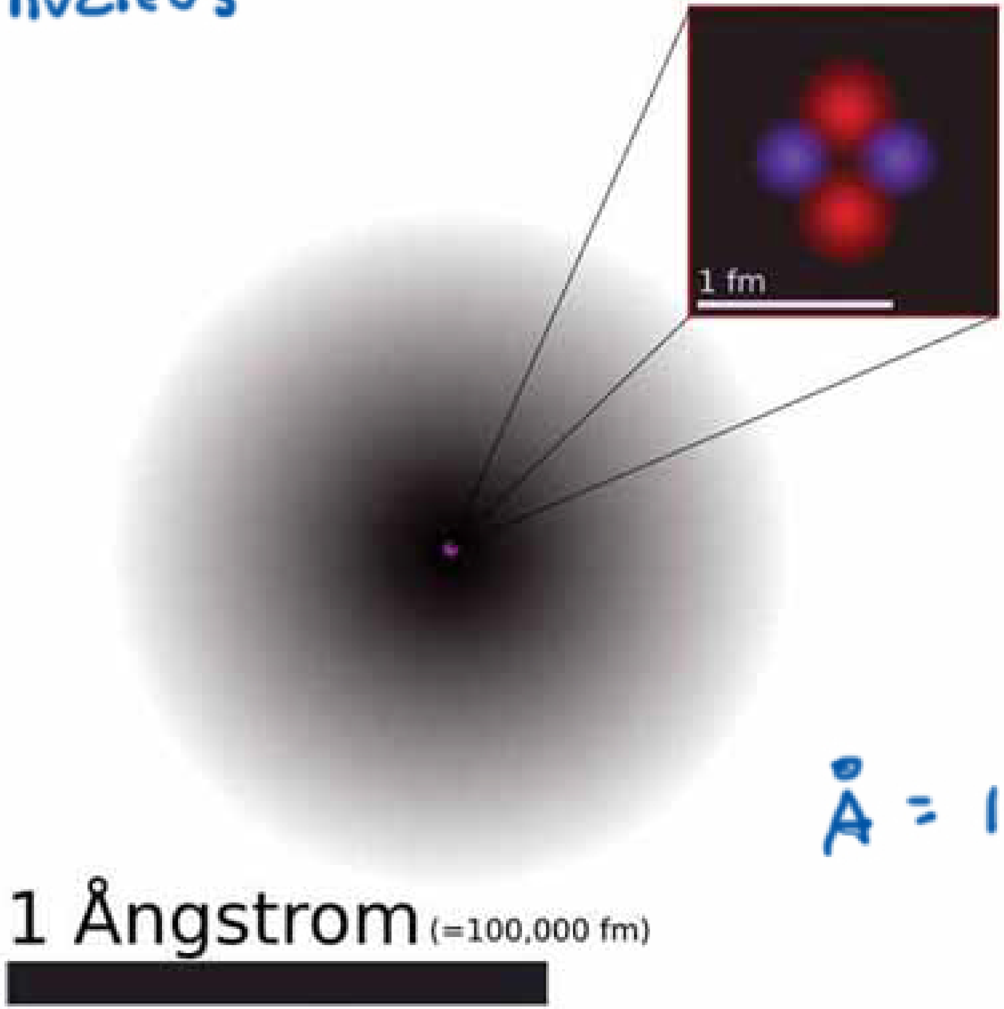
c. A double image of the substance

d. The substance appeared opaque through the 2nd polarizer

$$\text{specific rotation} = \frac{\text{observed rotation}}{d \, c}$$

Nuclear Physics

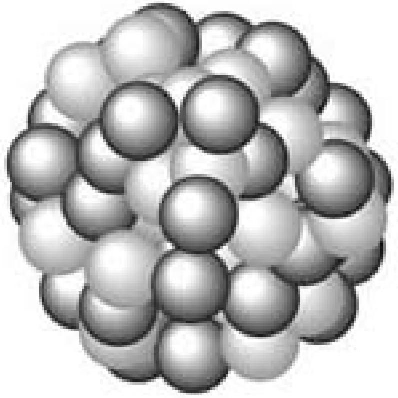
The nucleus



fm = 10^{-15} m

Å = 10^{-10} m

The Nucleus



$${}^{A}_{Z}\mathbf{X}$$

chemical symbol, *X*, for the element

atomic number, *Z*, equals the number of protons in the nucleus.

mass number, *A*, equals the number of nucleons (protons plus neutrons) in the nucleus.

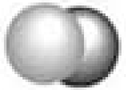
neutron number, $N = A - Z$

Isotopes *of an element have the same number of protons but a different number of neutrons in the nucleus, in other words, the same atomic number,* ***Z****, but different neutron number,* ***N****, and, therefore, different mass number,* ***A****.*

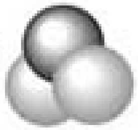
Isotopes of Hydrogen

${}^{1}_{1}\mathrm{H}$ 

normal hydrogen nucleus

${}^{2}_{1}\mathrm{H}$ 

deuterium nucleus

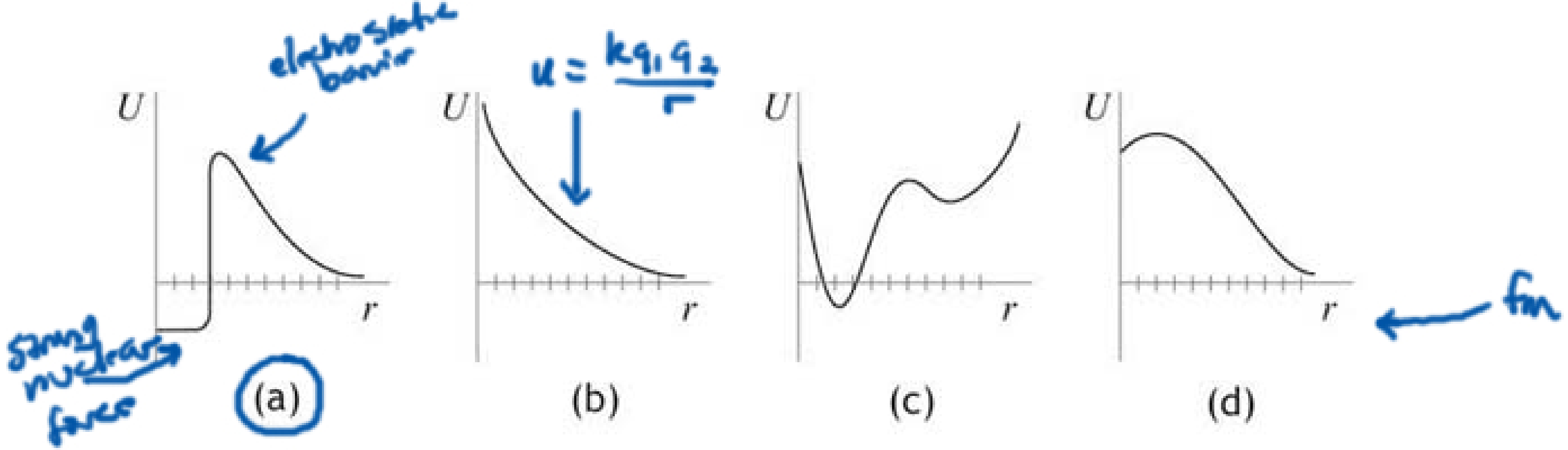
${}^{3}_{1}\mathrm{H}$ 

tritium nucleus

The femtometer (fm) is a convenient unit of length for nuclear physics because its value is on the order of nuclear radii:

$$1 \text{ fm} = 10^{-15} \text{ m}$$

Through observations of scattering experiments, nuclear physicists have developed a potential energy curve for the interaction of two protons. For a system of two protons, which of the the following is the best representation of potential energy versus separation in femtometers?



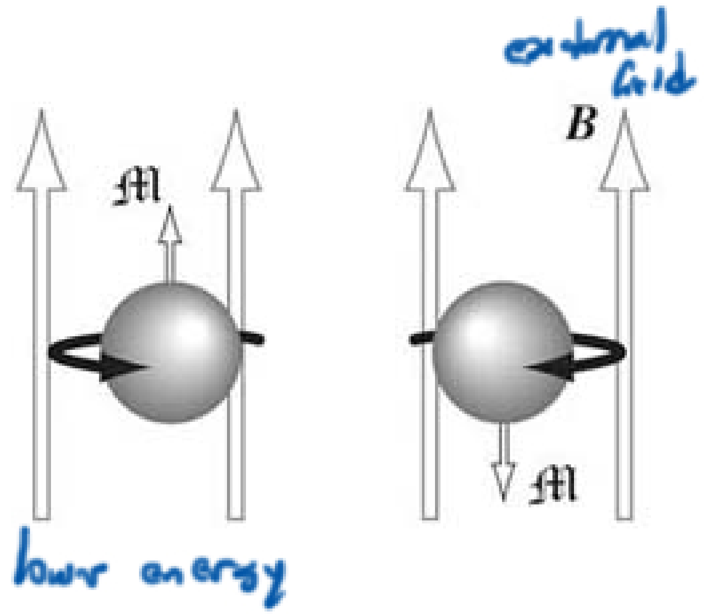
Nuclear Spin States

Nuclear spin quantum number, *I*.

Number of allowed spin states is *I* + 1.

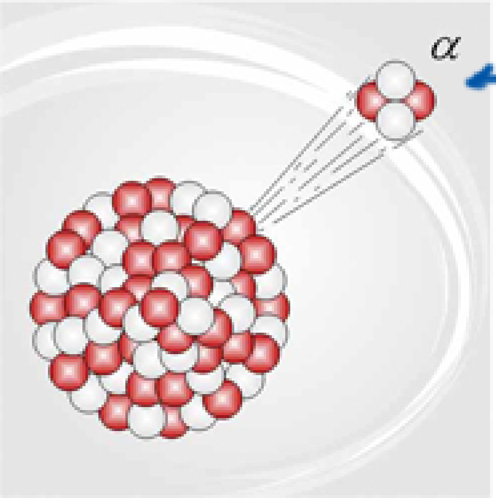
Spin states: – *I*, (– *I* + 1), . . . ,(– *I* + 1), *I*

Element	$^{1}_{1}H$	$^{2}_{1}H$	$^{12}_{6}C$	$^{13}_{6}C$
Spin Quant #, *I*	$\frac{1}{2}$	1	0	$\frac{1}{2}$
# of states	2	3	0	2

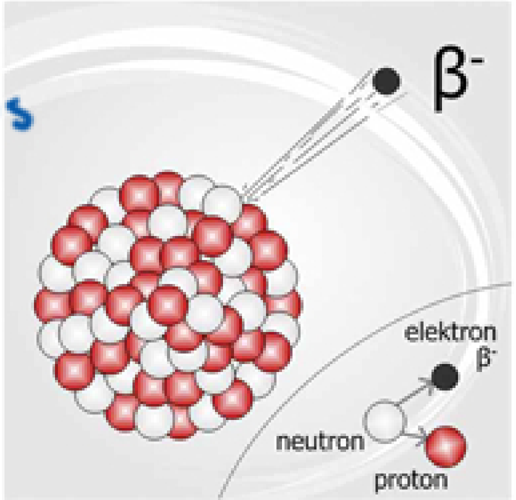


An applied magnetic field splits the two spin states of a proton into states of unequal energy. Energy is lower for the state in which the spin magnetic moment is aligned with the external field.

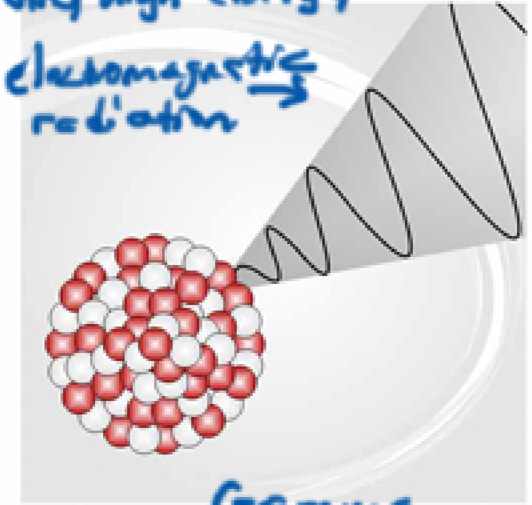
nuclear decay



← helium nucleus



very high energy electromagnetic radiation

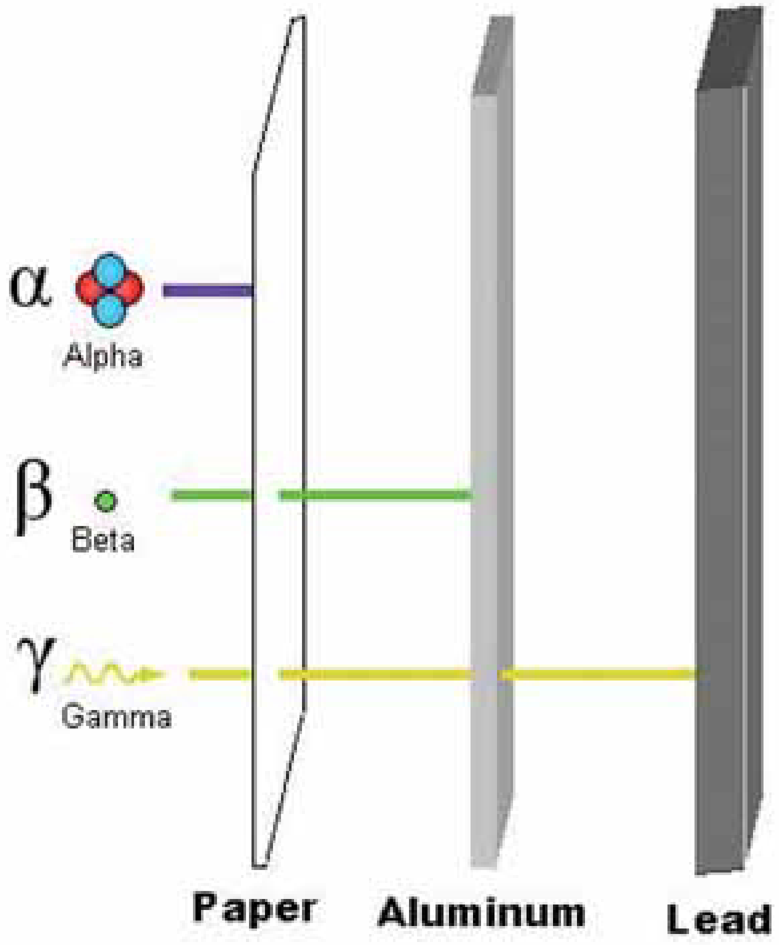


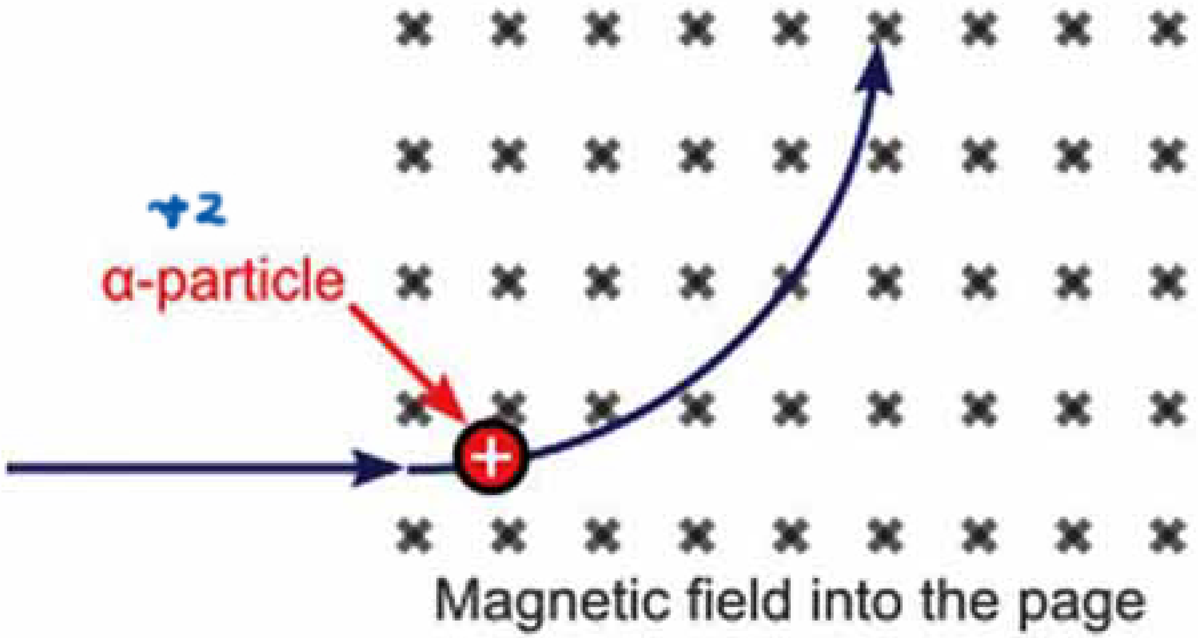
Gamma

Beta Decay

β^- electron

β^+ positron


α
Alpha
β
Beta
γ
Gamma
Paper
Aluminum
Lead


+2
α-particle
Magnetic field into the page

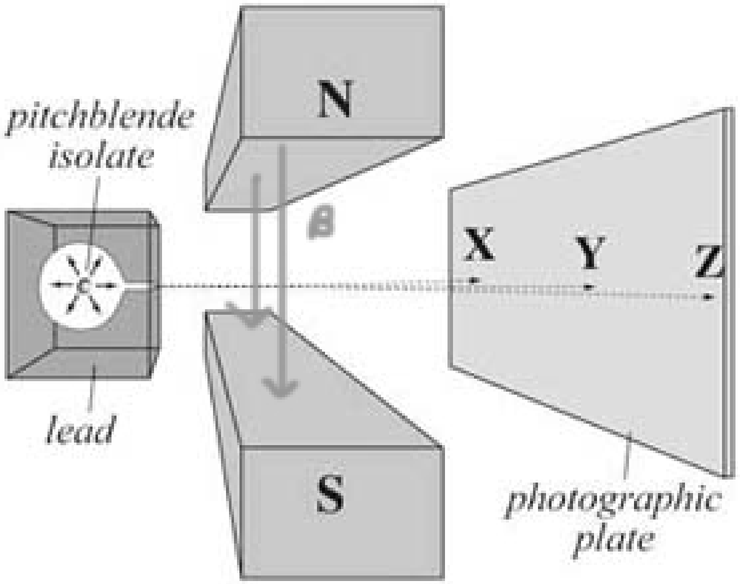
Radioactive Decay

Decay	Description
Alpha Decay $^{226}_{88}\mathrm{Ra} \longrightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$	A nuclei undergoes **alpha decay** by emitting an α **particle**, which is identical to a helium nucleus ($^{4}_{2}\mathrm{He}^{2+}$, two protons and two neutrons). *Z* decreases by 2 and *A* decreases by 4.
Beta Decay $^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\beta^{-} + \bar{\nu}$ (antineutrino)	In β^- **decay**, a β^- **particle**, which is a high speed electron, and an **antineutrino**, $\bar{\nu}$, are emitted. A neutron changes into a proton in the nucleus (*Z* increases by 1 with *A* unchanged).
$^{13}_{7}\mathrm{N} \longrightarrow {}^{13}_{6}\mathrm{C} + {}^{0}_{1}\beta^{+} + \nu$ (neutrino)	In β^+ **decay**, a β^+ **particle**, (a **positron**, the anti-particle of the electron) and a **neutrino**, *ν*, are emitted. A proton changes into a neutron in the nucleus (*Z* decreases by 1 with *A* unchanged).
Electron Capture $^{7}_{4}\mathrm{Be} + {}^{0}_{-1}\mathrm{e} \longrightarrow {}^{7}_{3}\mathrm{Li} + \nu$	In **electron capture**, a nucleus captures one of the atom's own electrons, changing a proton to a neutron (*Z* decreases by 1 with *A* unchanged), and a **neutrino**, *ν*, is emitted.
Gamma Decay $^{125}_{53}\mathrm{I}^{*} \longrightarrow {}^{125}_{53}\mathrm{I} + \gamma$	**Gamma decay** occurs when a nucleus in an excited energy state (very often as the result of a prior decay event) emits a very high energy photon, a **gamma ray**, as it transitions to a lower energy state.

β emitters
^{32}P ^{35}S ^{14}C
^{3}H ← radiolabels

PET scanning
$^{18}_{9}F \longrightarrow {}^{18}_{8}O + \beta^{+} + \nu$
$\beta^{+} + \beta^{-} \longrightarrow \gamma$

An isolate of the ore, pitchblende, is significantly radioactive. When the radiation is deflected by the magnetic field at right and detected photographically, one component of the radiation, **X**, is found to bend into the plane of the figure, and another component, **Z**, bends out of the plane. The third component, **Y**, is not affected by the magnetic field. Which of the following describes the components?



a. **X** is composed of β^- rays; **Y** is γ rays; and **Z** is α rays

b. **X** is composed of α rays; **Y** is anti-neutrinos; and **Z** is β^- rays

c. **X** is composed of β^+ rays; **Y** is neutrinos; and **Z** is β^- rays

d. **X** is composed of α rays; **Y** is γ rays; and **Z** is β^- rays

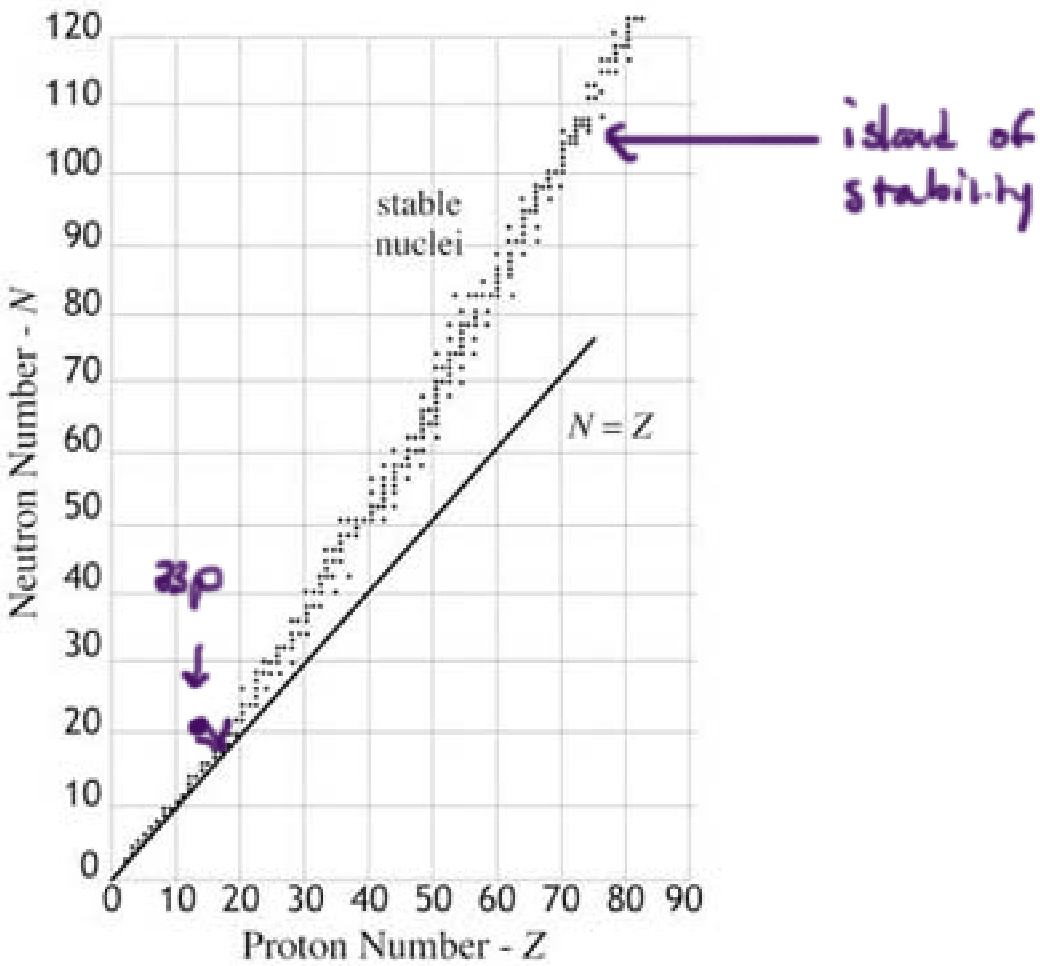
Stable nuclides are represented by a narrow band of proton-to-neutron ratios on the graph of neutron number vs. proton number. Nuclei falling outside this region are unstable and subject to radioactive decay. Unstable nuclei above the band are said to be neutron rich, and those below it are neutron poor. What type of decay would be expected for the isotope of phosphorus, $^{33}_{15}P$?

a. α decay

b. β^+ decay

c. β^- decay

d. electron capture



Activity and Half-Life

$$A = \frac{\Delta N}{\Delta t} = -\lambda N$$

A = activity (disintegrations per second)
N = number of radioactive nuclei
t = time
λ = decay constant

$A = -\lambda N$

just like (rate = k[X])

1st order kinetics

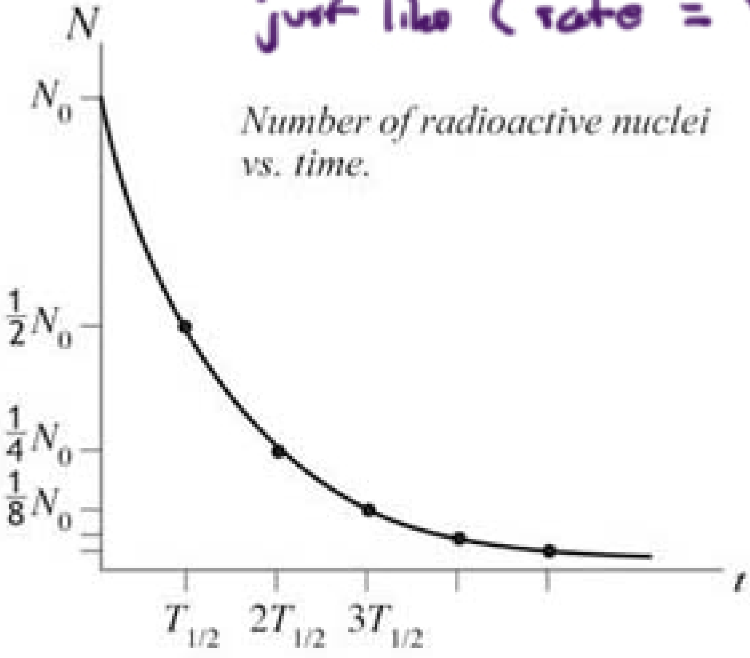
exponential decay

$$N = N_0 e^{-\lambda t}$$

N = number of radioactive nuclei
N_0 = number of nuclei initially present
λ = decay constant
t = time

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

$T_{1/2}$ = half-life
λ = decay constant

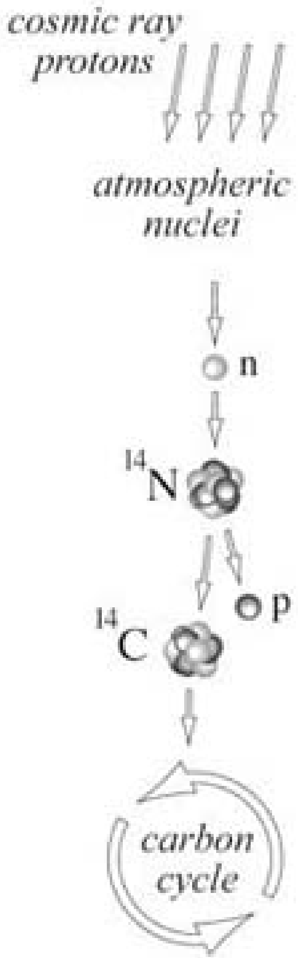


Number of radioactive nuclei vs. time.

The half-life is the time required for half of an amount of a given radionuclide to undergo decay.

half lives	1	2	3	4	5
# remaining	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$

In the upper atmosphere, cosmic ray protons collide with nuclei causing reactions that produce neutrons. These neutrons in turn lead to the transformation of ^{14}N into ^{14}C. This is a continuous process which maintains a ratio of ^{14}C to ^{12}C in the atmosphere that is fairly constant through millenia. After an organism dies, it ceases exchanging carbon with the atmosphere, and the ratio ^{14}C to ^{12}C decreases through the beta decay of ^{14}C which has a half-life of 5730 years.



1 2 3

$\frac{1}{2}$ $\frac{1}{4}$ $\frac{1}{8}$

Measuring the level of radioactive decay of ^{14}C in the preserved epidermal tissue of a mummy, it was found to sustain 20% of the activity of living tissue. What is the approximate age of the mummy?

a. 1400 yrs

b. 13,500 yrs

c. 25,000 yrs

d. 30,000 yrs

Mass / Energy Equivalence in Nuclear Processes

Reaction Energy

$$Q = \Delta m c^2$$

Q = total energy released in a nuclear process
Δm = mass difference between products and reactants
c = speed of light (3×10^8 m/s)

The rest mass of nucleons in a stable nucleus is lower.

Binding Energy

free protons — free neutrons — nucleus

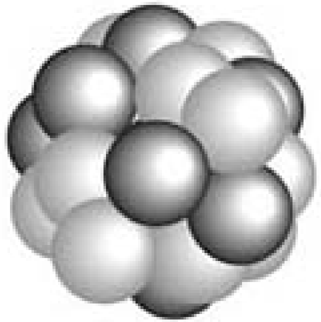
$$E_b = [Z m_p + N m_n - M_{Nu}] \times c^2$$

mass defect

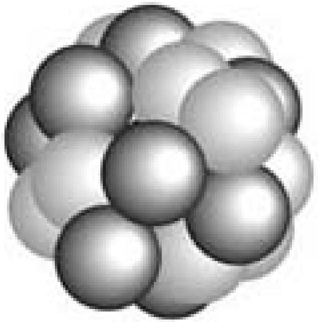
$$E_b = [Z m_p + N m_n - M_{Nu}] \times 931.5 \text{ MeV/u}$$

E_b = nucleus binding energy
Z = atomic number
m_p = free proton mass
N = neutron number
m_{Nu} = free neutron mass
M_{Nu} = atomic mass of combined nucleus
c = speed of light (3×10^8 m/s)

The rest mass of a free neutron is 1.008665, and the rest mass of a free proton is 1.007276 u. Which of these two nuclei is the most stable?



$^{23}_{11}\mathbf{Na}$
22.989770 u



$^{23}_{12}\mathbf{Mg}$
22.994127 u

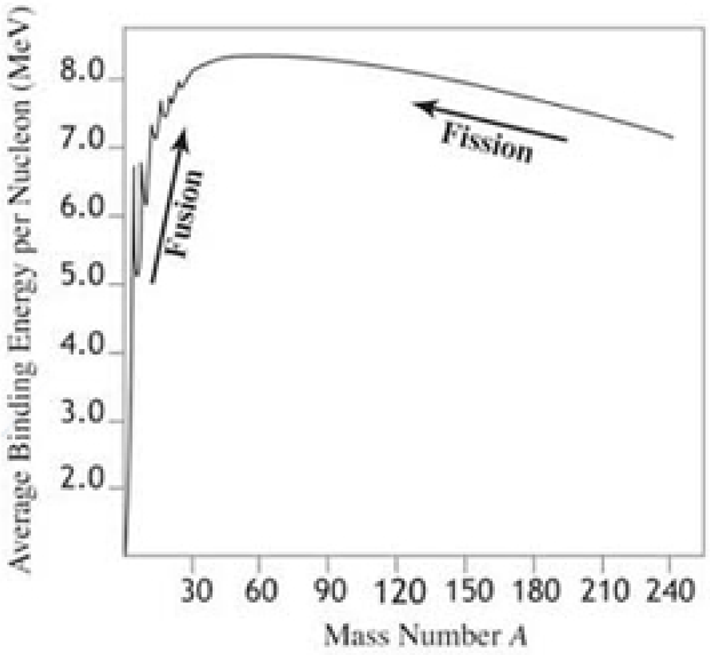
a. $^{23}_{11}\mathbf{Na}$

b. $^{23}_{12}\mathbf{Mg}$

c. Their stabilities are equal.

d. $^{23}_{12}\mathbf{Mg}$ is more stable against α decay, while $^{23}_{11}\mathbf{Na}$ is more stable against β^- decay.

Fusion and Fission



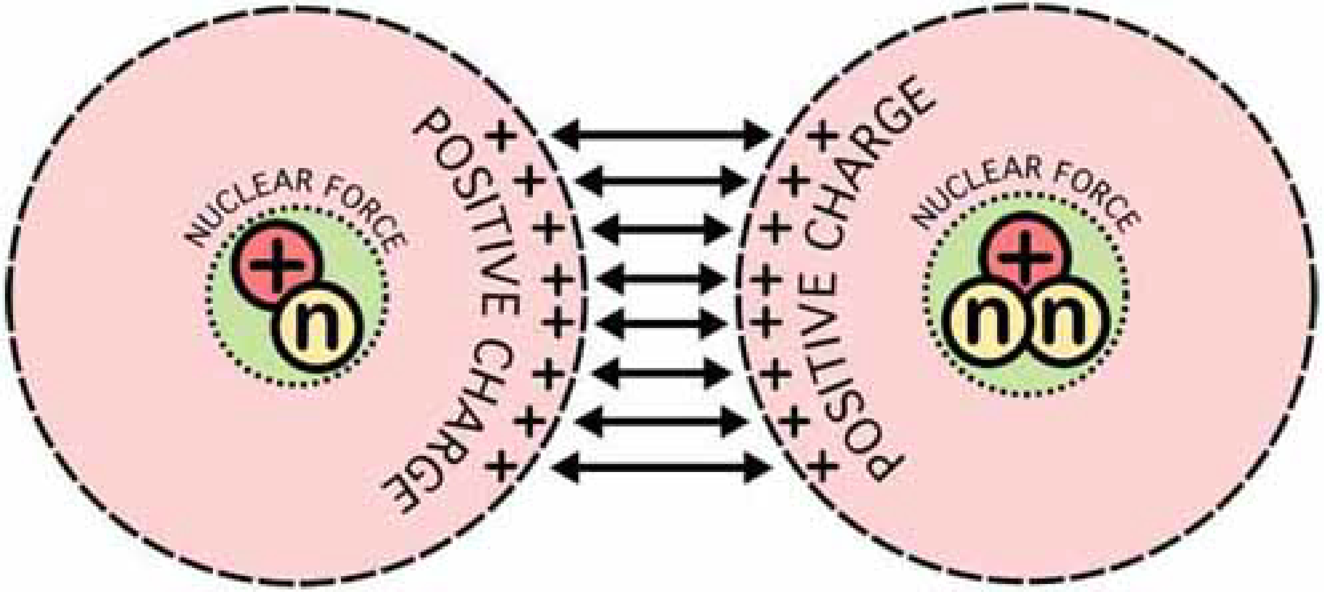
Fusion combines two light nuclei to produce a heavier nuclei. It requires very high concentrations of reactants and high temperature conditions.

$$^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$

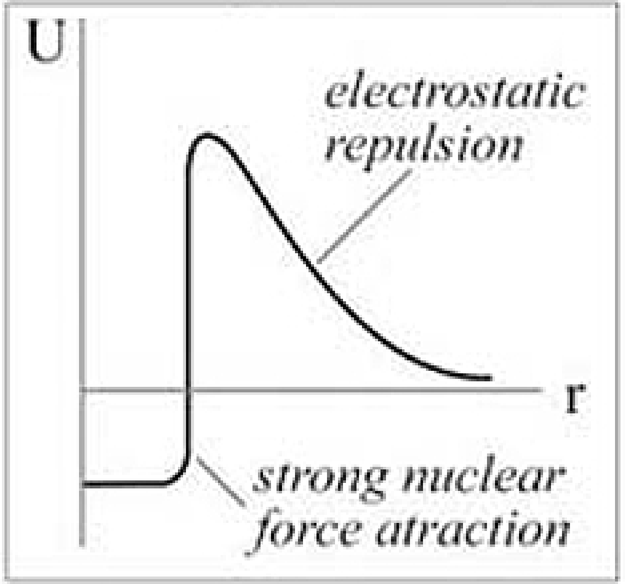
Fission is the splitting of a heavy nucleus into two lighter nuclei. In the reaction below, note that a neutron initiates fission and that more neutrons are produced by fission. Thus a nuclear *chain reaction* is possible if the mass of $^{235}_{92}\mathrm{U}$ is sufficiently concentrated (critical mass).

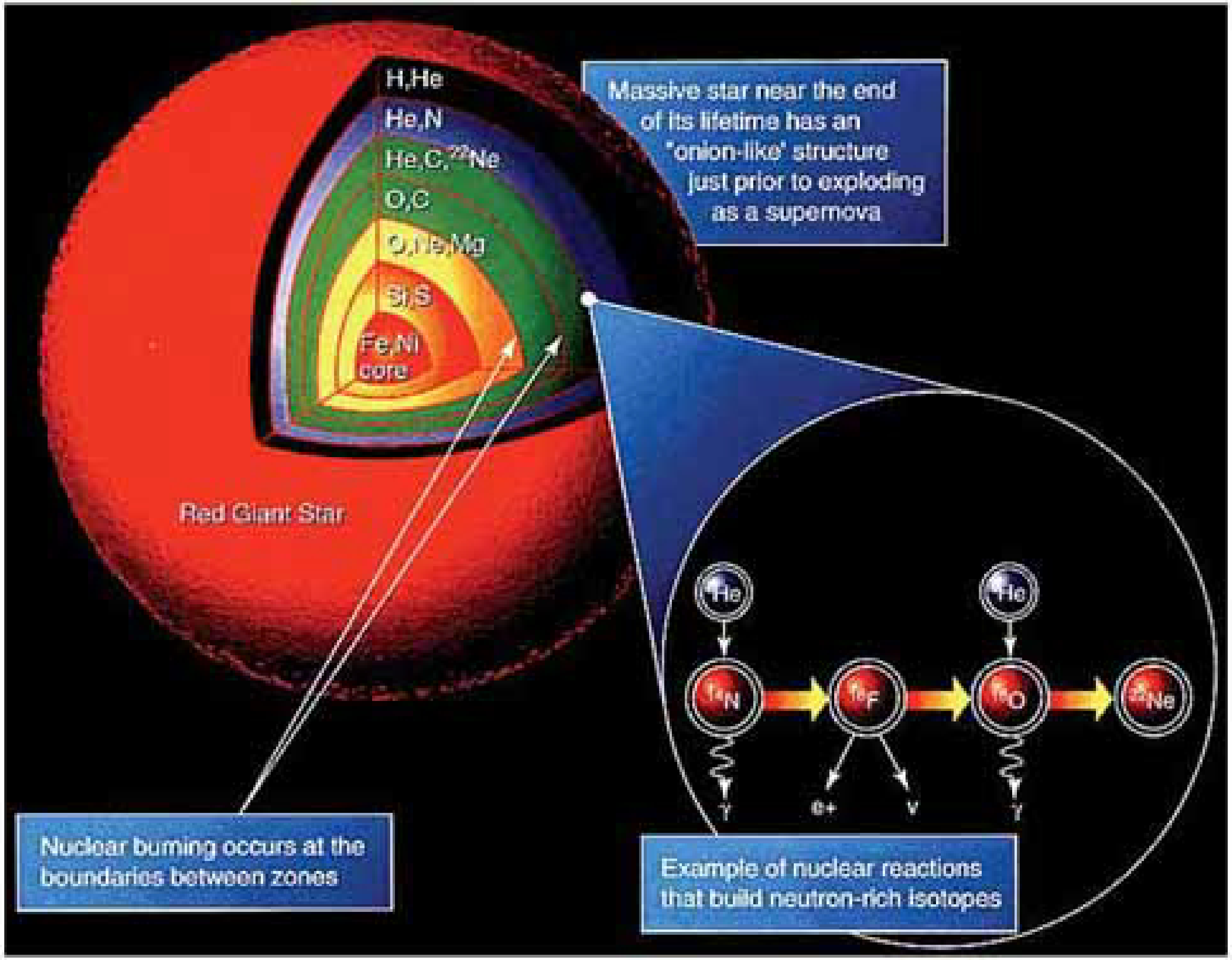
$$^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \longrightarrow {}^{140}_{54}\mathrm{Xe} + {}^{94}_{38}\mathrm{Sr} + 2\,{}^{1}_{0}\mathrm{n}$$

↑
thermal (slow)
neutron


NUCLEAR FORCE
POSITIVE CHARGE
NUCLEAR FORCE
POSITIVE CHARGE
n
n n

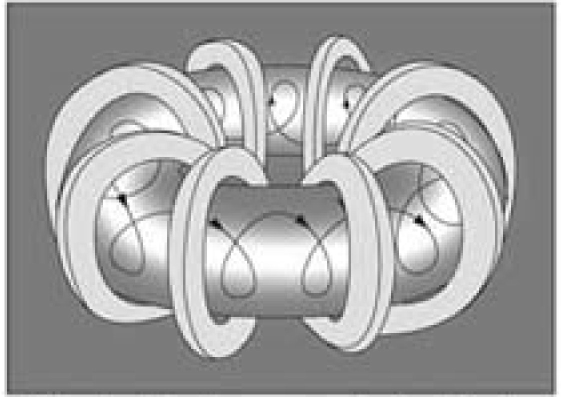
The graph at right shows potential energy vs. distance between a deuteron and a tritium nucleus. Before fusion can occur, the electrostatic force of repulsion between the two nuclei must be overcome by their kinetic energy. This allows the colliding nuclei to approach within a few femtometers (fm) (1 fm = 10^{-15} m) of each other where the strong nuclear force prevails and fusion can occur.




H,He
He,N
He,C,^{22}Ne
O,C
O,Ne,Mg
Si,S
Fe,Ni core
Massive star near the end of its lifetime has an "onion-like" structure just prior to exploding as a supernova
Red Giant Star
He
^{14}N
F
O
Ne
γ
e+
ν
Nuclear burning occurs at the boundaries between zones
Example of nuclear reactions that build neutron-rich isotopes

Most nuclear fusion reactions achieved in the laboratory require the reactant atoms to be in the form of a plasma. Plasma is a very high temperature form of matter in which the atoms are completely ionized. Which of the following best describes the required plasma temperature for the sustained fusion of deuterium and tritium?

$${}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$



The helical magnetic field of a tokamak fusion reactor traps the high temperature plasma, preventing it from contacting the container walls.

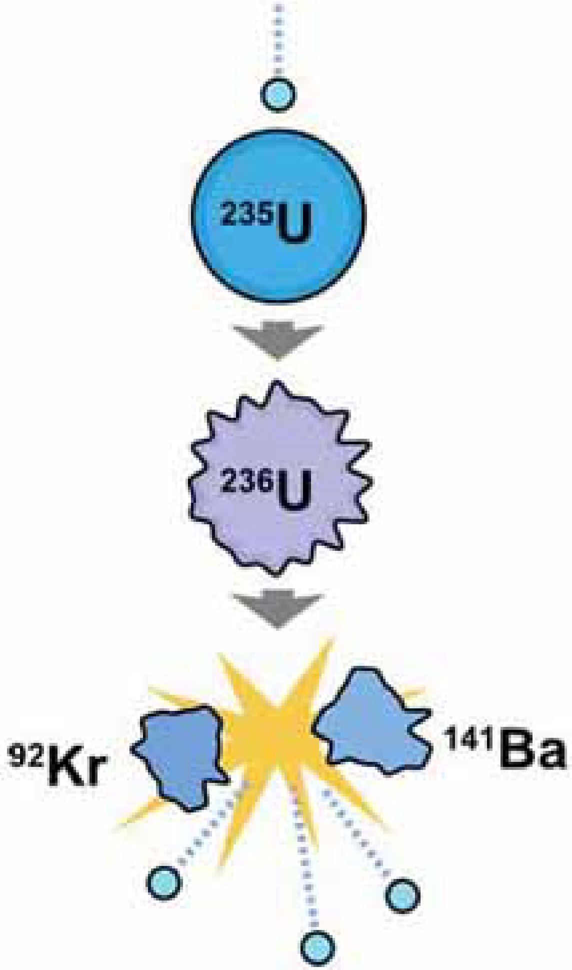
a. the temperature necessary to fully ionize deuterium and tritium

b. a temperature great enough for the kinetic energy of two typical colliding nuclei to exceed their electrostatic potential energy barrier

c. the core temperature of the sun

d. the temperature where the average particle speed produces a magnetic force greater than the electrostatic repulsion between nuclei

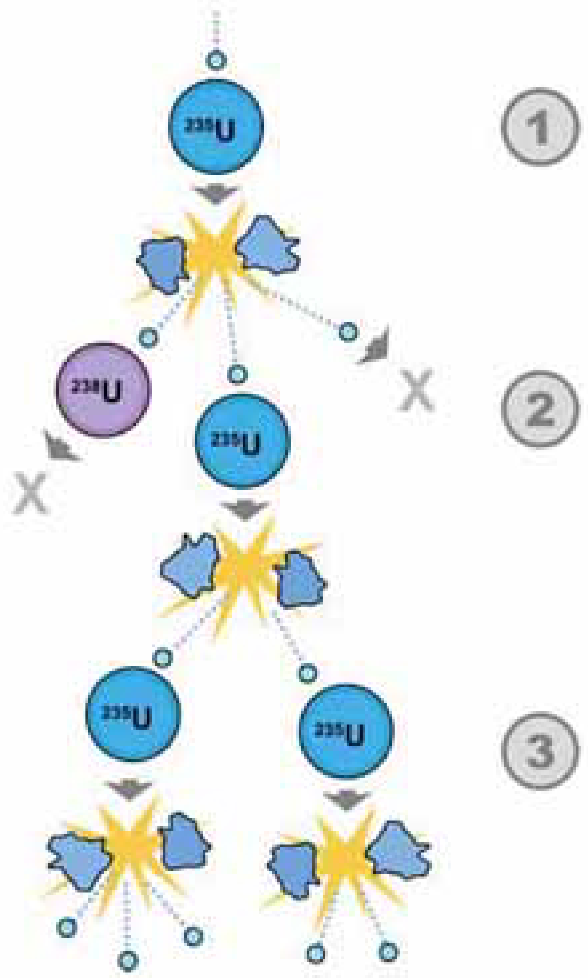
critical mass -
high enough ^{235}U %
to sustain chain
reaction



^{235}U

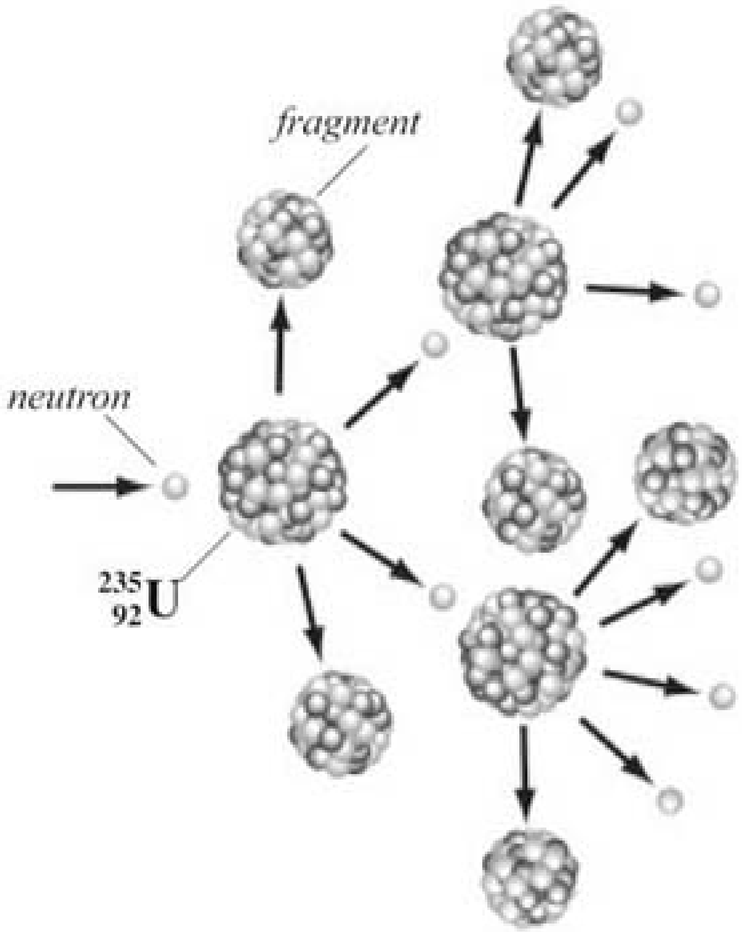
most uranium is
^{238}U

enriched uranium
high ^{235}U



235U
1
238U
235U
X
X
2
235U
235U
3

Chain Reaction Fission of $^{235}_{92}U$



The $^{235}_{92}U$ nucleus undergoes fission after capturing a thermal neutron. The fission reaction produces two fission fragments and, depending upon the particalar daughter nuclei, two or three neutrons. These neutrons, in turn, can trigger the fission of other nuclei, leading to

Typical $^{235}_{92}U$ Fission Reactions

$$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2\,^{1}_{0}n$$

$$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$$

$$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{132}_{50}Sn + ^{101}_{42}Mo + 3\,^{1}_{0}n$$