Module 1

Fundamentals of Mechanics & Electrostatics

Session Slides with Notes

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

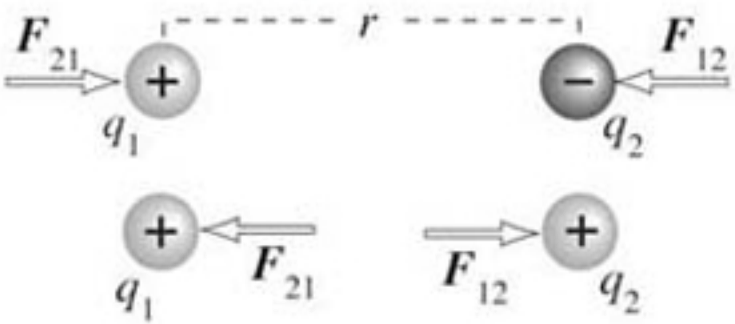
Temperature & Heat Flow
1st Law of Thermodynamics
Stoichiometry
Thermochemistry
2nd Law & Heat Engines
Chemical Thermodynamics & Equilibrium
The States of Matter
Organic Physical Properties
Solutions
Acids & Bases
Organic Reaction Mechanisms
Amino Acids & Protein Structure

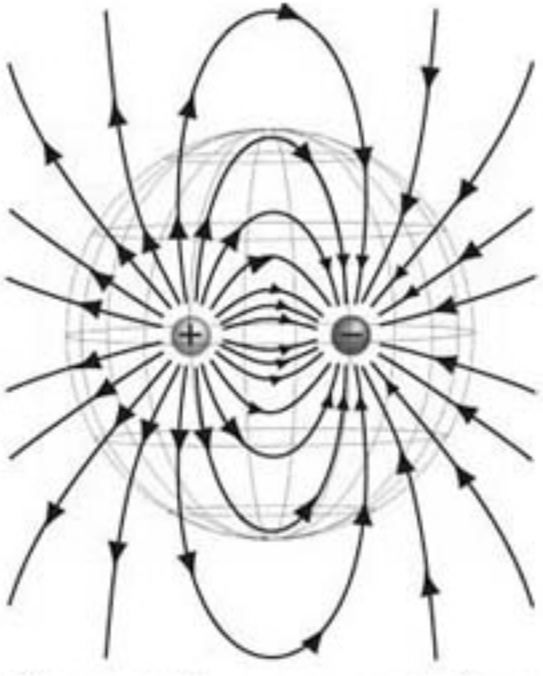
↓

Biochemistry

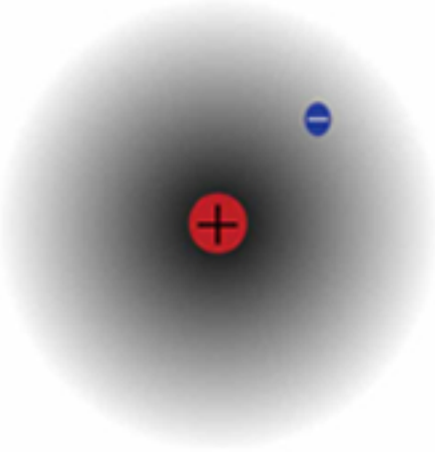
Fluid Mechanics
Deformations, Oscillations & Vibrations
Waves

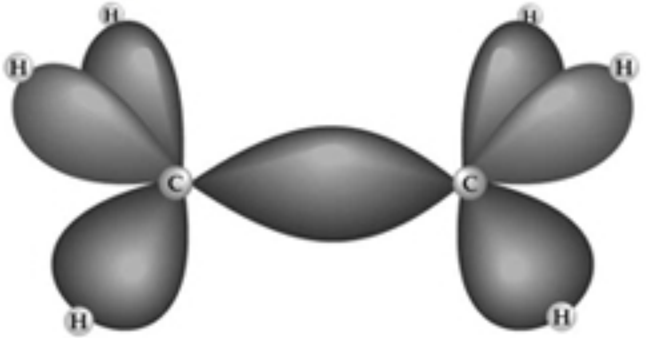
Physics

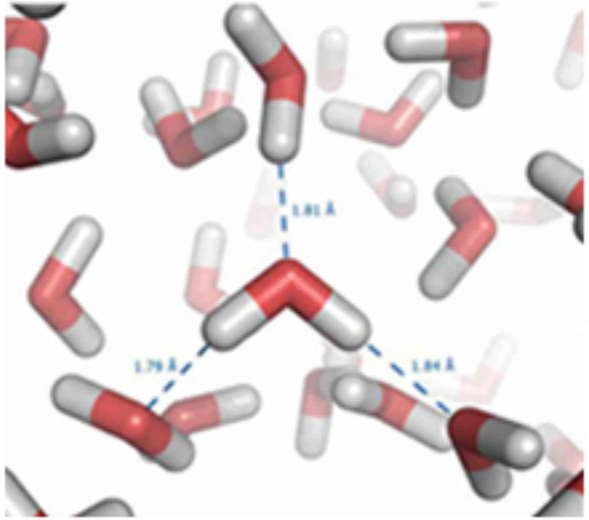




Chemistry







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

$$v = v_0 + at$$

$$\Delta v = at$$

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

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

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

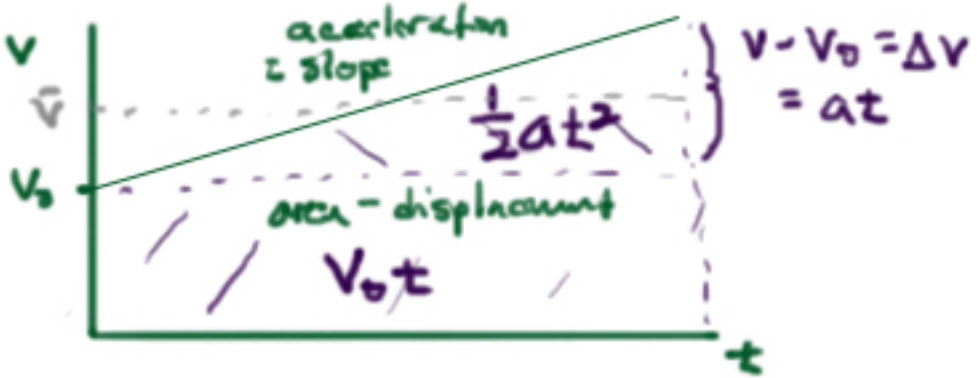
$$v^2 - v_0^2 = 2a\,\Delta x$$

work ↓

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

$$\Delta KE = \text{work}$$

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



mass (kg)

Force (kg·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 $1\,N\cdot m = 1\,J$
(energy)

Power $\cdot$ $1\,J/s = 1$ 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

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

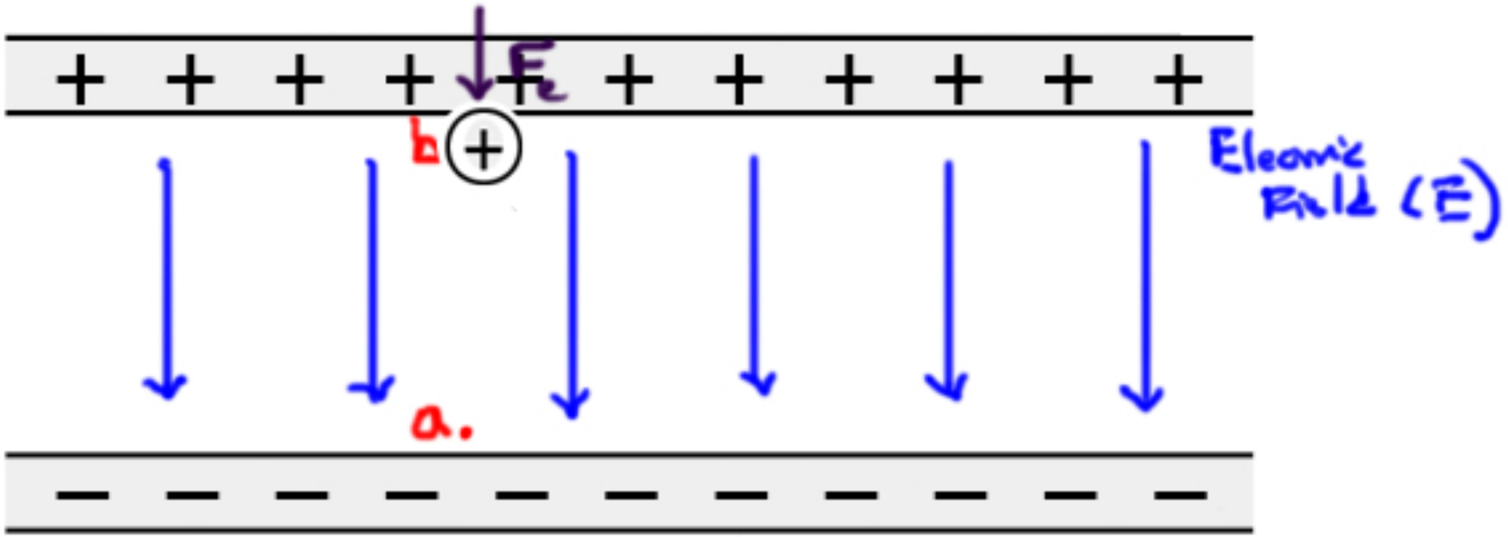
$$P = Fv$$

Electric, q
charge
- Coulombs
(C)

Electric Field, E
N/C

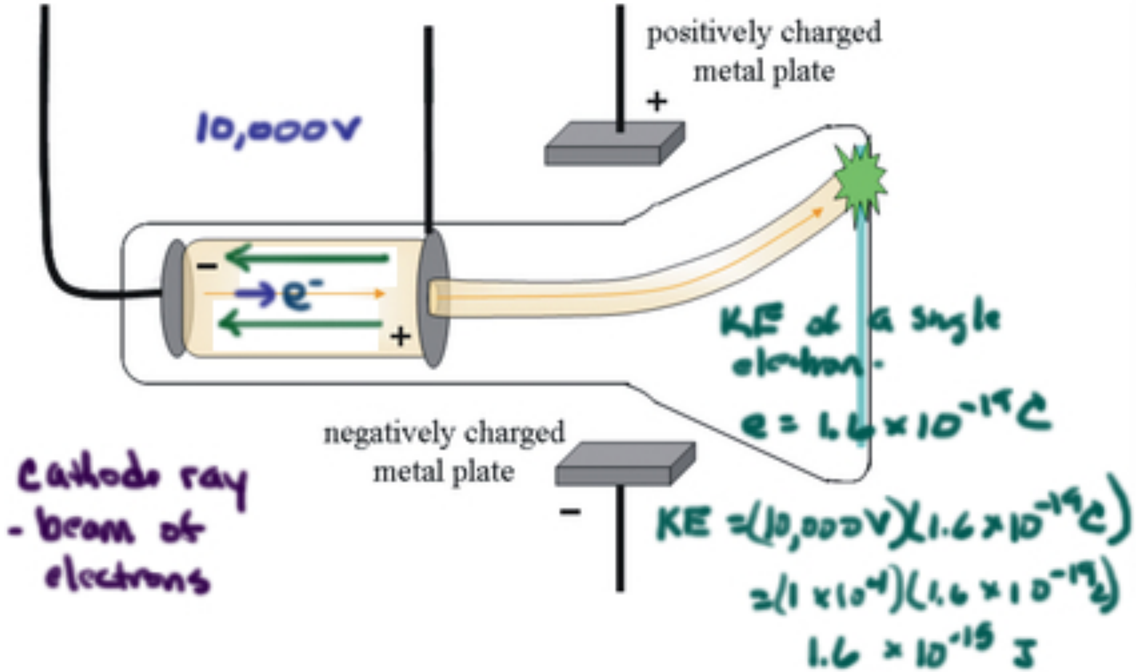
Potential Difference
V, voltage
Volt - J/C

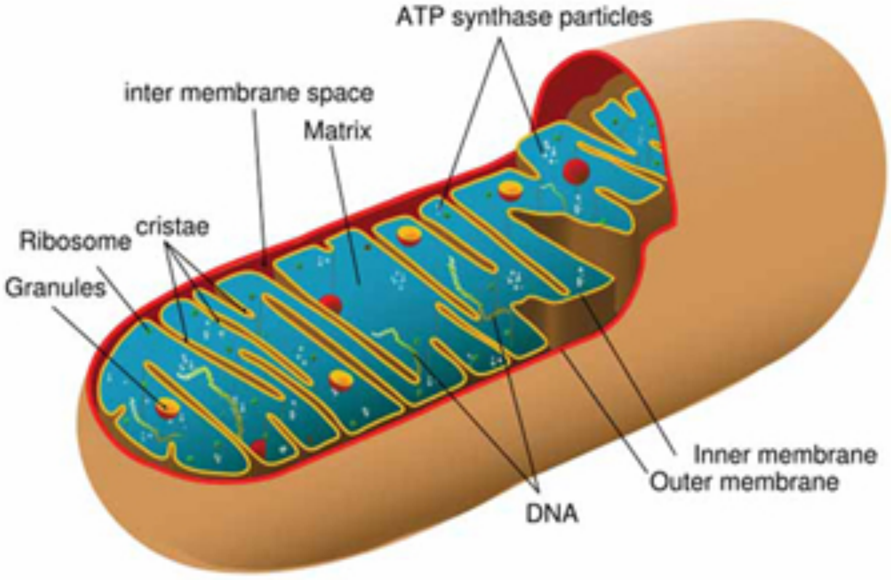
uniform electric field

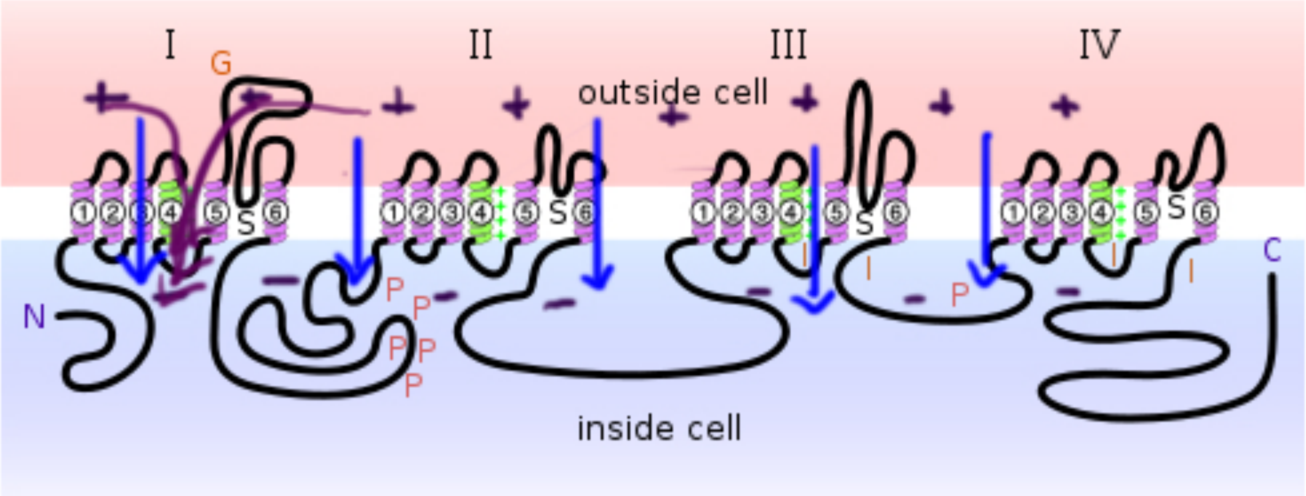


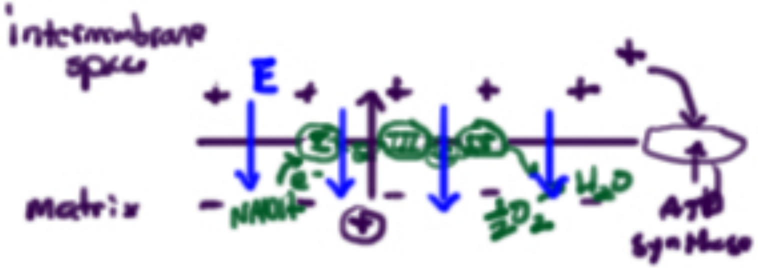
Kinematics	Dynamics	Work & Energy
constant acceleration	$F = Eq$	$V = Ed$
	$F = ma$	$1\ \text{volt} = J/C$

work = force · distance

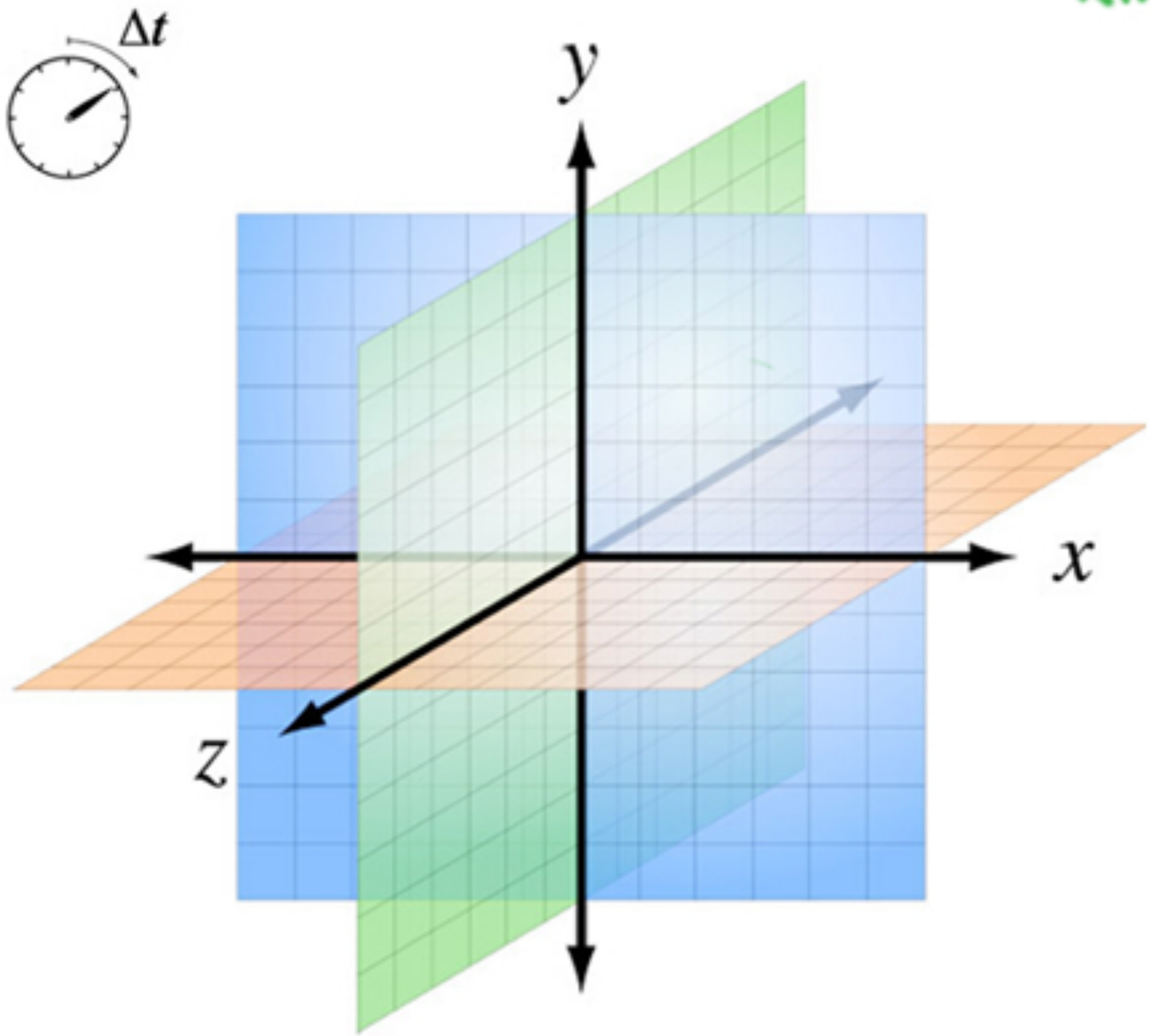

10,000V
positively charged
metal plate
+
e⁻
negatively charged
metal plate
−
Cathode ray
- beam of electrons
KE of a single electron -
e = 1.6 × 10⁻¹⁹ C
KE = (10,000V)(1.6 × 10⁻¹⁹ C)
= (1 × 10⁴)(1.6 × 10⁻¹⁹)
1.6 × 10⁻¹⁵ J

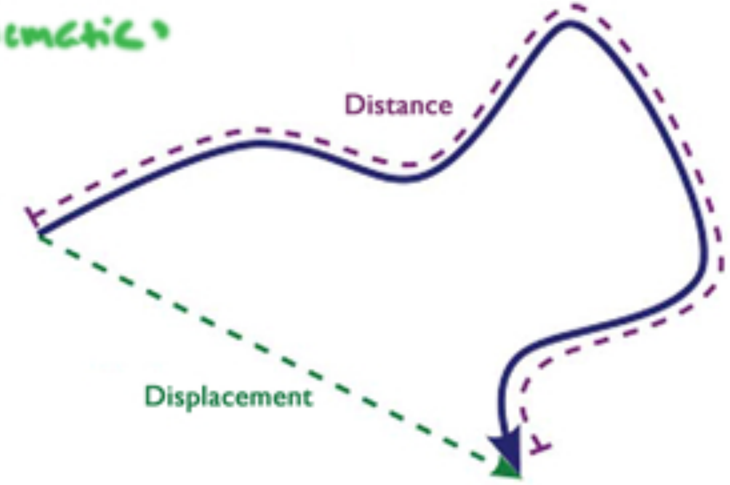

ATP synthase particles
inter membrane space
Matrix
Ribosome
cristae
Granules
Inner membrane
Outer membrane
DNA


I
II
III
IV
G
outside cell
S
N
P
C
inside cell


intermembrane space
E
matrix
NADH
e⁻
½O₂
H₂O
ATP synthase

Kinematics





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

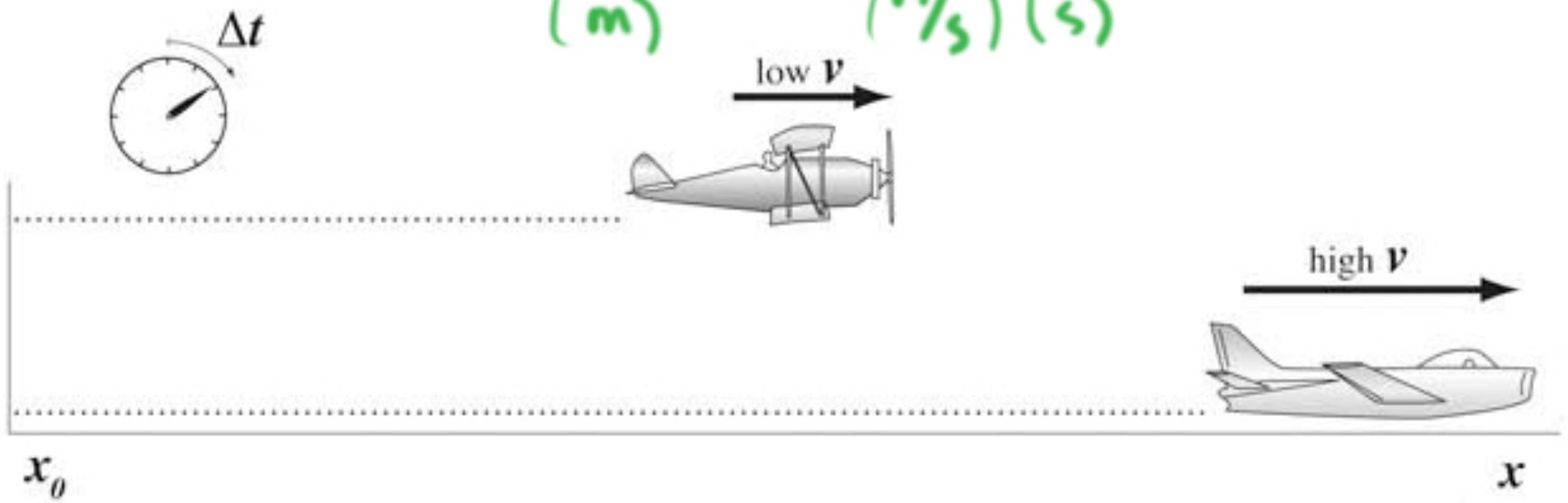
Velocity

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

$\bar{v}$ = average velocity
$x\text{-}x_0$ = 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
$v\text{-}v_0$ = change in velocity
Δt = change in time

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

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

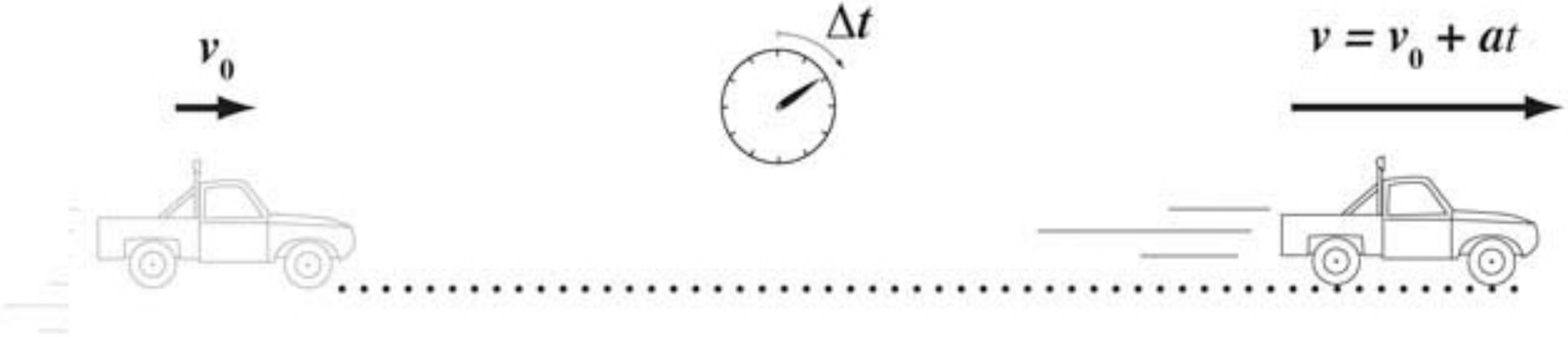
Velocity as a Function of Time

Constant acceleration

$$v = v_0 + at$$

$\Delta v = at$

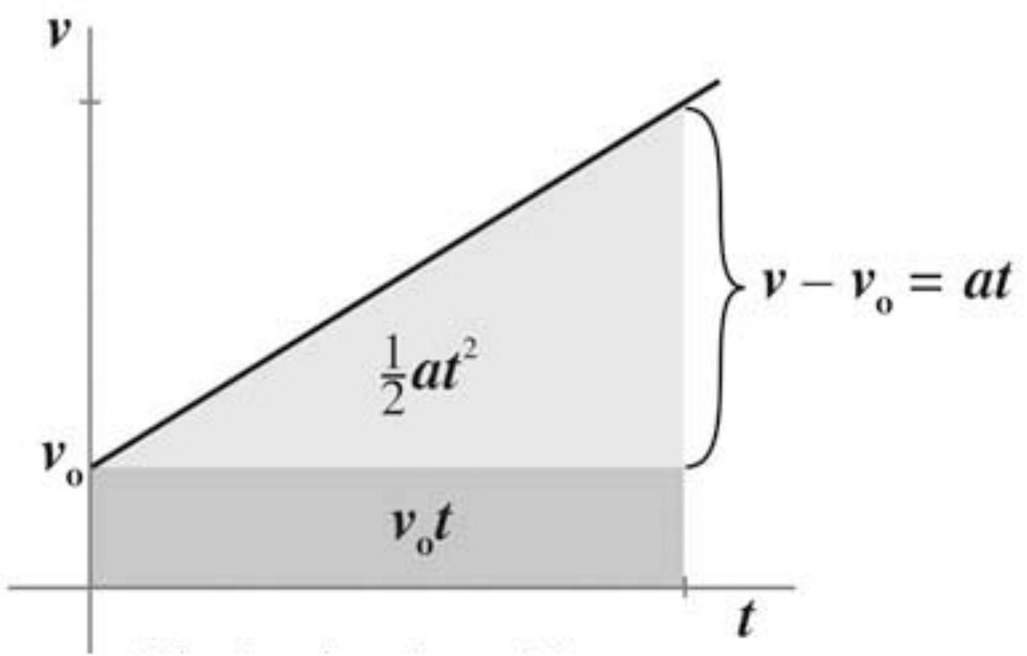
v	=	velocity
v_0	=	initial velocity
a	=	acceleration (constant)
t	=	time



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?

$\Delta x = 12 m$

$V_0 = 0$

$a = 10 m/s^2$

$\Delta x = V_0 t + \frac{1}{2} a t^2$

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

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

$t^2 = 2.4$

$t = 1.5 s$

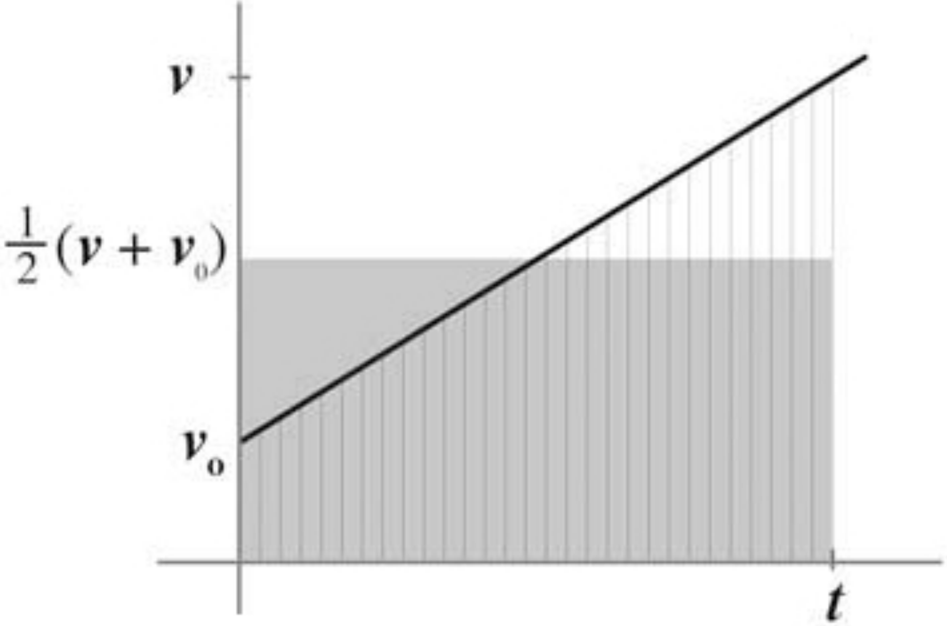
Displacement is the Product of Average Velocity and Time

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

constant acceleration

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

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



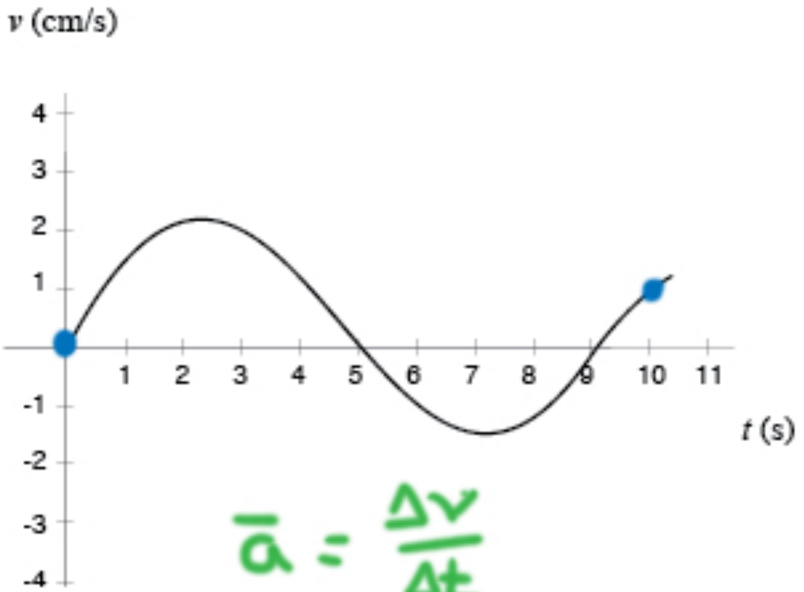
Velocity as a Function of Displacement

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

constant acceleration

v	=	velocity
v_0	=	initial velocity
a	=	acceleration (constant)
x-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

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

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

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

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

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

a. 20 m

b. 45 m

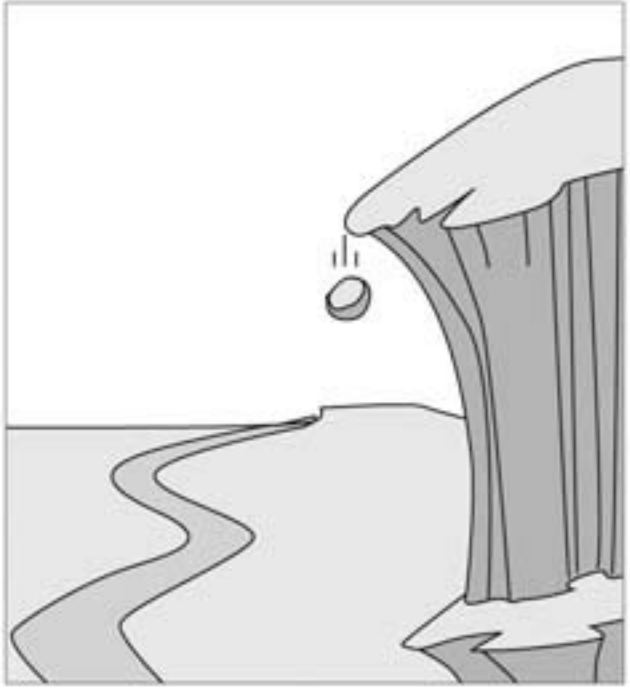
c. 30 m

d. 90 m

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

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

$$= 45 m$$



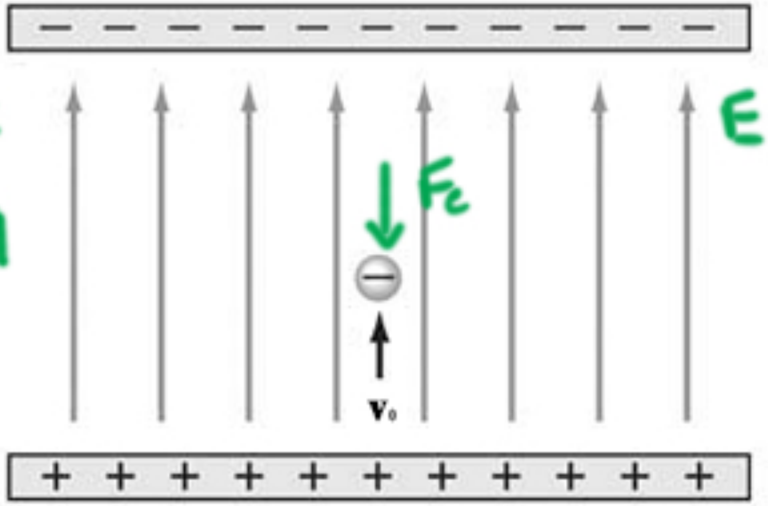
If he throws it upwards at 30 m/s
How long to catch it again?

Constant F

$F = Eq$

Constant a

$F = ma$



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

g

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

$\Delta v = at$

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

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

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

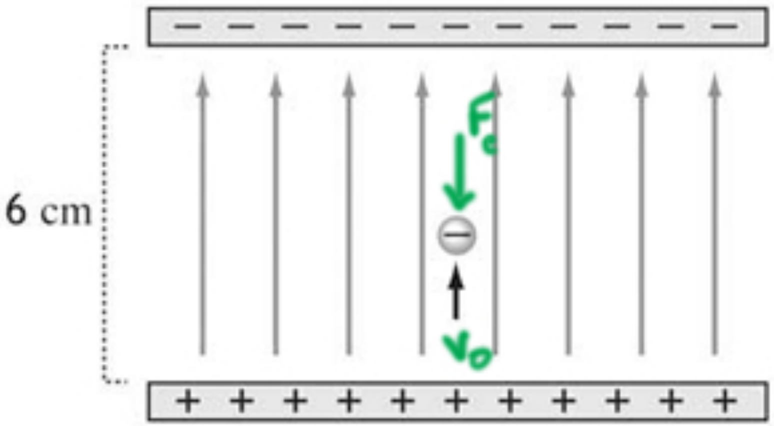
The application of heat causes emission of an electron by the positive plate of a parallel plate capacitor. The electron moves into the uniform electric field between the plates with an initial velocity of 2.0×10^3 m/s perpendicular to the plate. The electron undergoes an acceleration of magnitude 4.0×10^7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

a. 2.0×10^{-5} s

b. 5.0×10^{-5} s

c. 1.0×10^{-4} s

d. 4.0×10^{-4} s



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

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

Projectile Motion

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

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

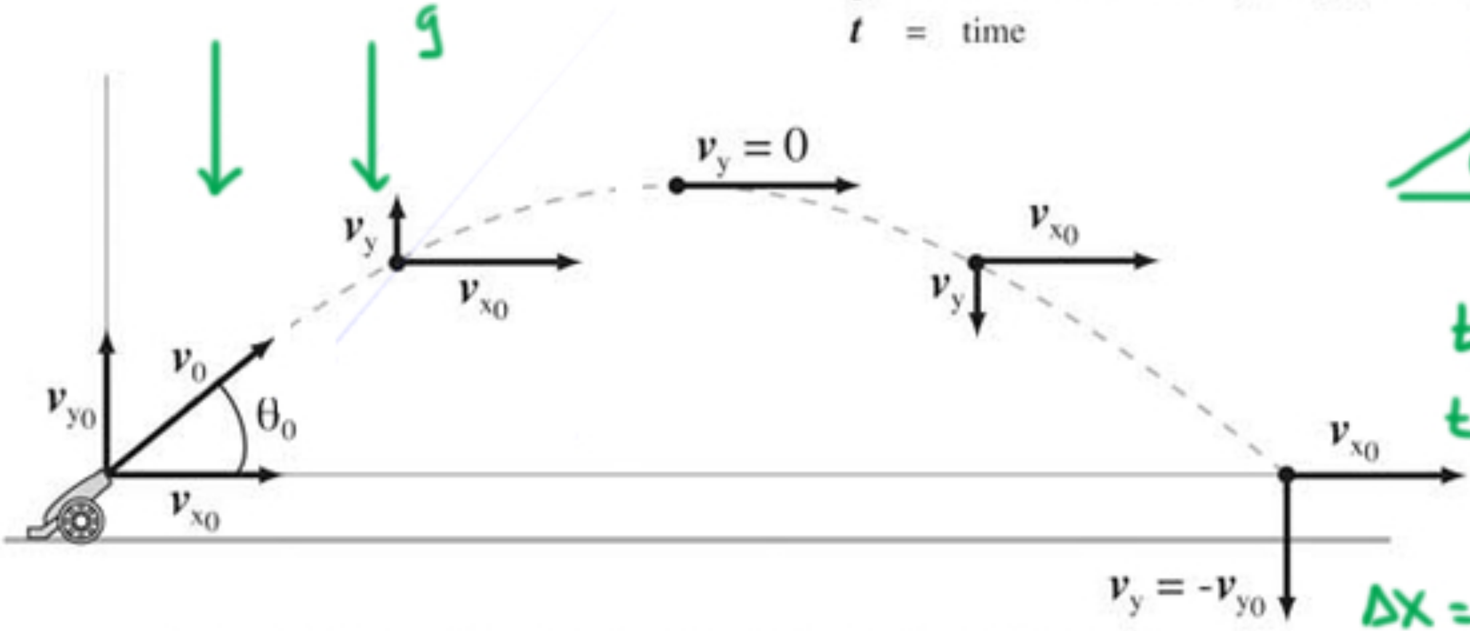
$$v_y = v_{y_0} - gt$$

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

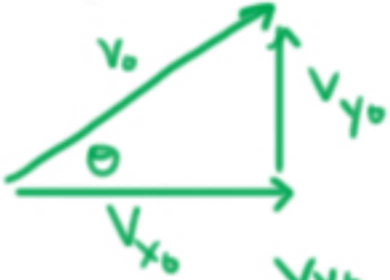
$V_{y_0} = V_0 \sin\theta$

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

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



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



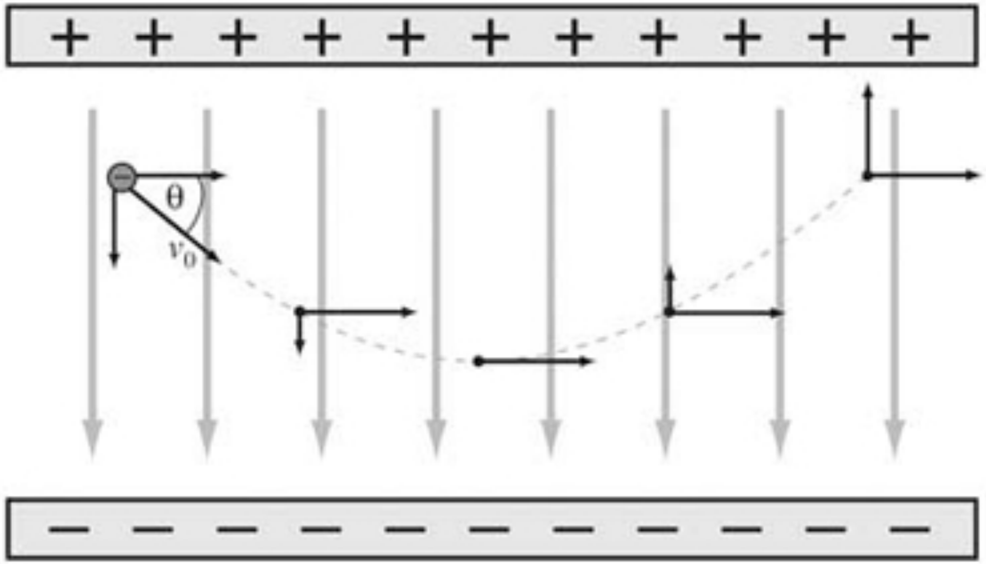
$t_{peak} = \frac{V_{y_0}}{g}$

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

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

range

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?

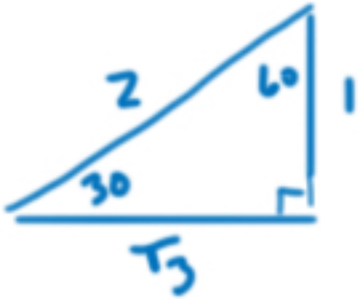


a. uniform circular motion

b. constant velocity

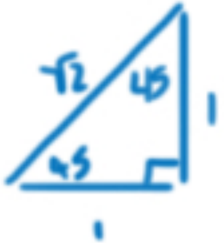
c. constant speed

d. parabolic motion

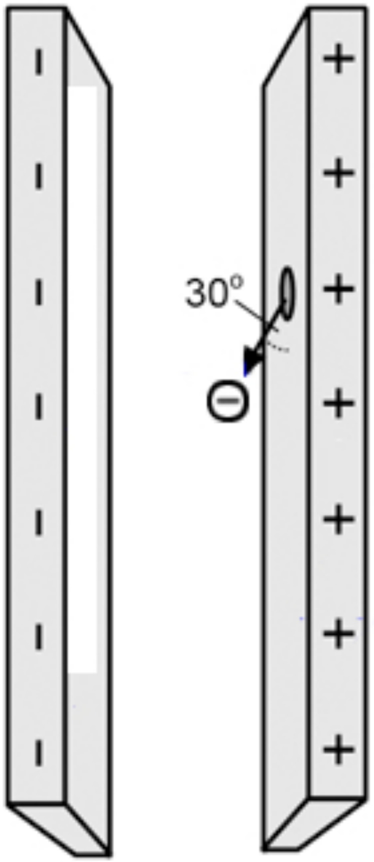


$\sin 30^\circ = \cos 60^\circ = \frac{1}{2}$

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



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

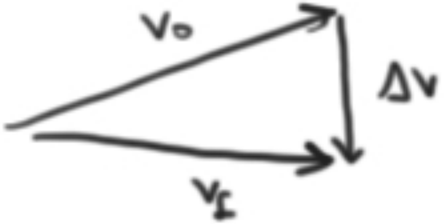


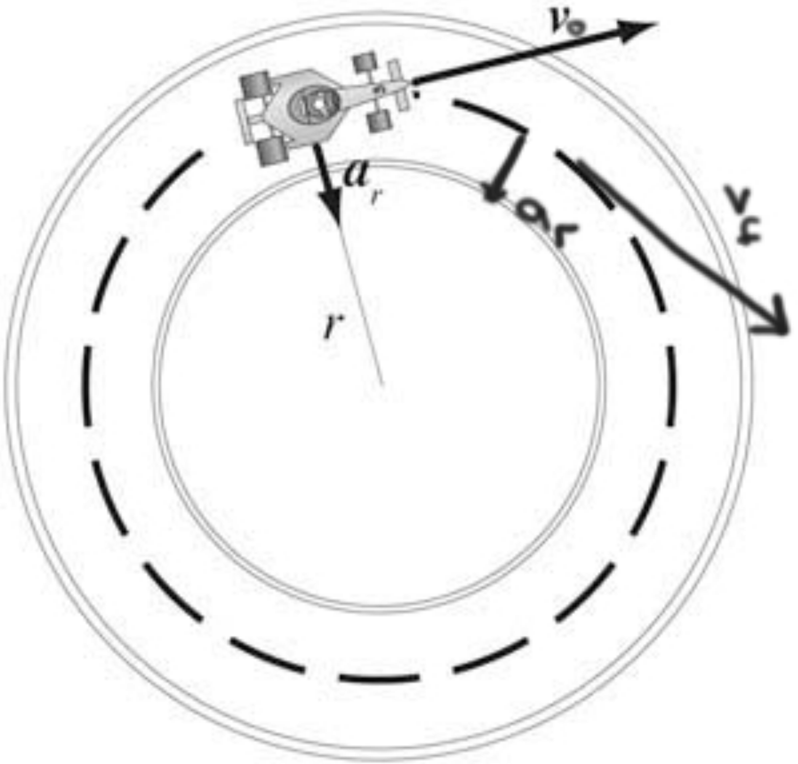
$v_\perp = v_0 \sin 30^\circ$

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

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?

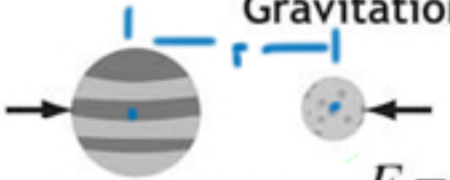
- Because F_r is always ⊥ to displacement, it performs <u>no work</u>

Dynamics and Newton's Laws

The Classical Fundamental Forces

Gravitation

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

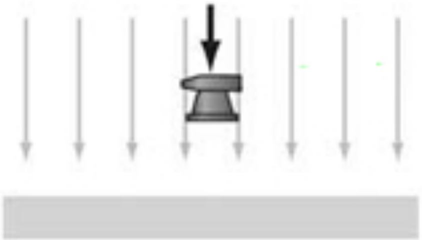


$$F = G\frac{m_1 m_2}{r^2}$$

Gravitational force between two masses

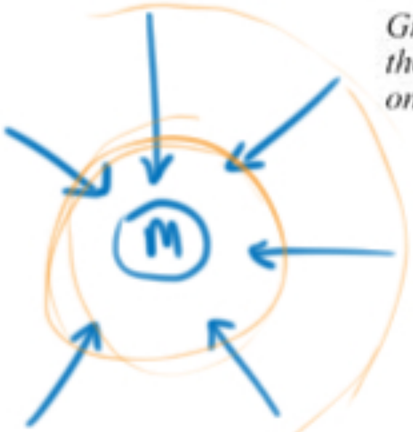
inverse square law forces

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



$$W = mg$$

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

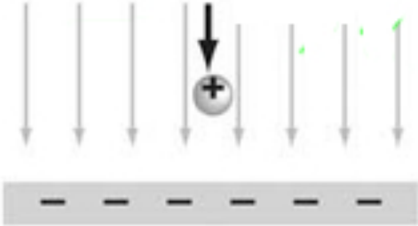


Electromagnetism

Electrostatic Force

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

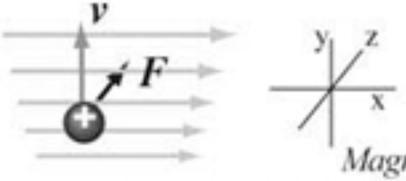
Electrostatic force between two point charges



$$F = Eq$$

Electrostatic force on a point charge within a uniform electric field

Magnetic Force



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

Magnetic force on a point charge moving through a magnetic field

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

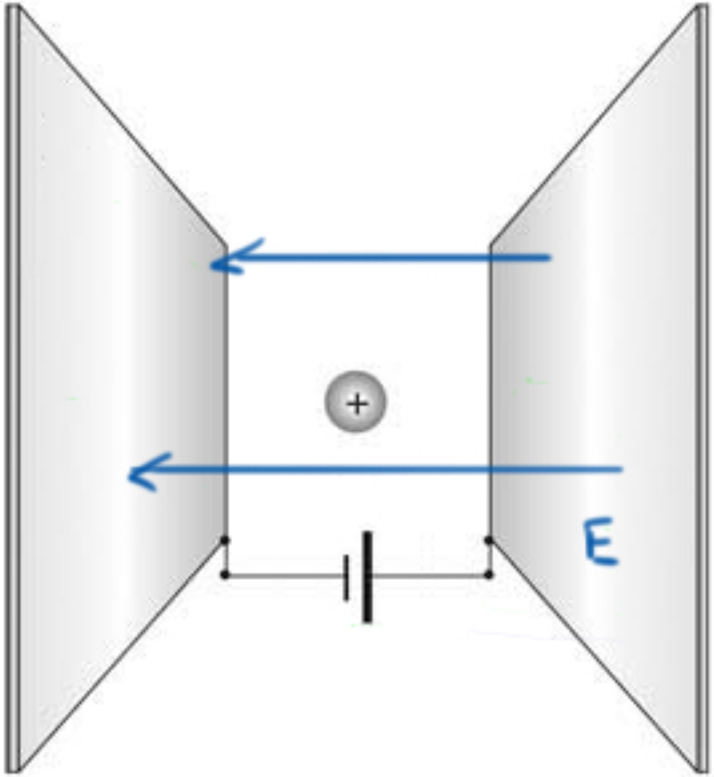
★

$$F = ma$$

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?



$F = ma$

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

$a = 0.5 m/s^2$

$\Delta v = a \Delta t$

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

$= 2 m/s$

a. 0.08 m/s

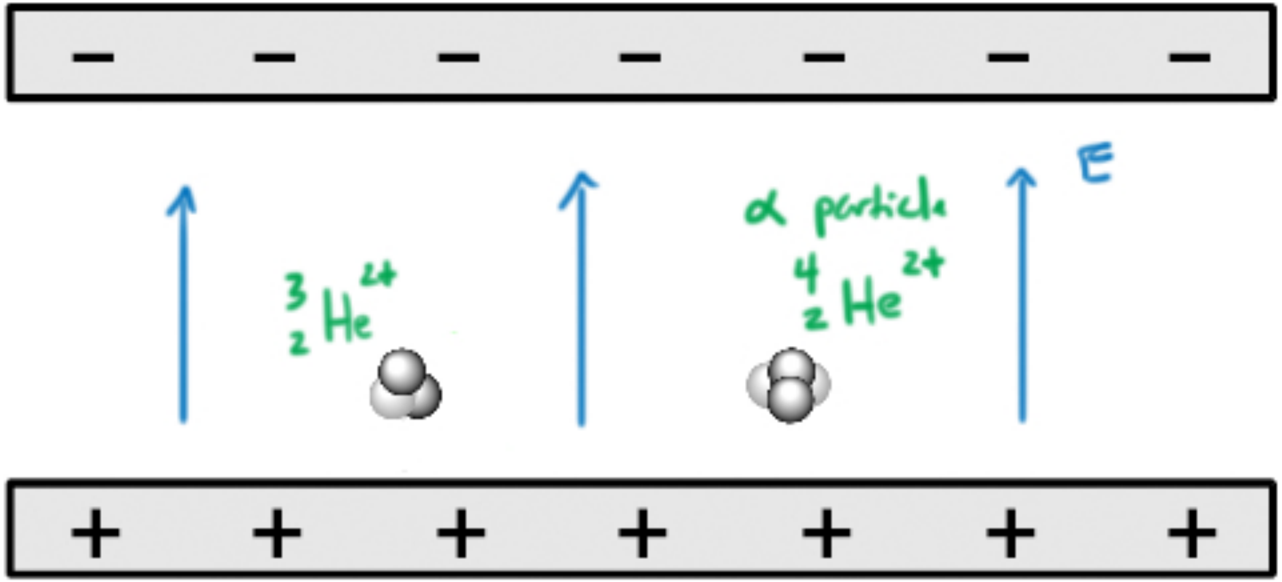
b. 0.5 m/s

c. 2.0 m/s

d. 8.0 m/s

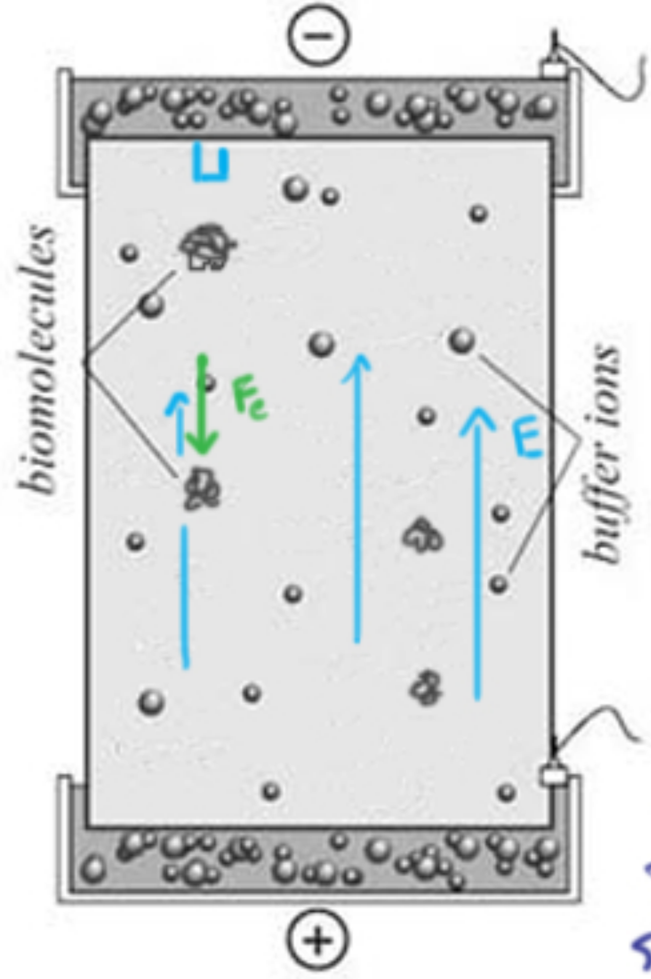
$^{4}_{2}He^{2+}$ and $^{3}_{2}He^{2+}$ are released from rest near the ⊕ plate

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)

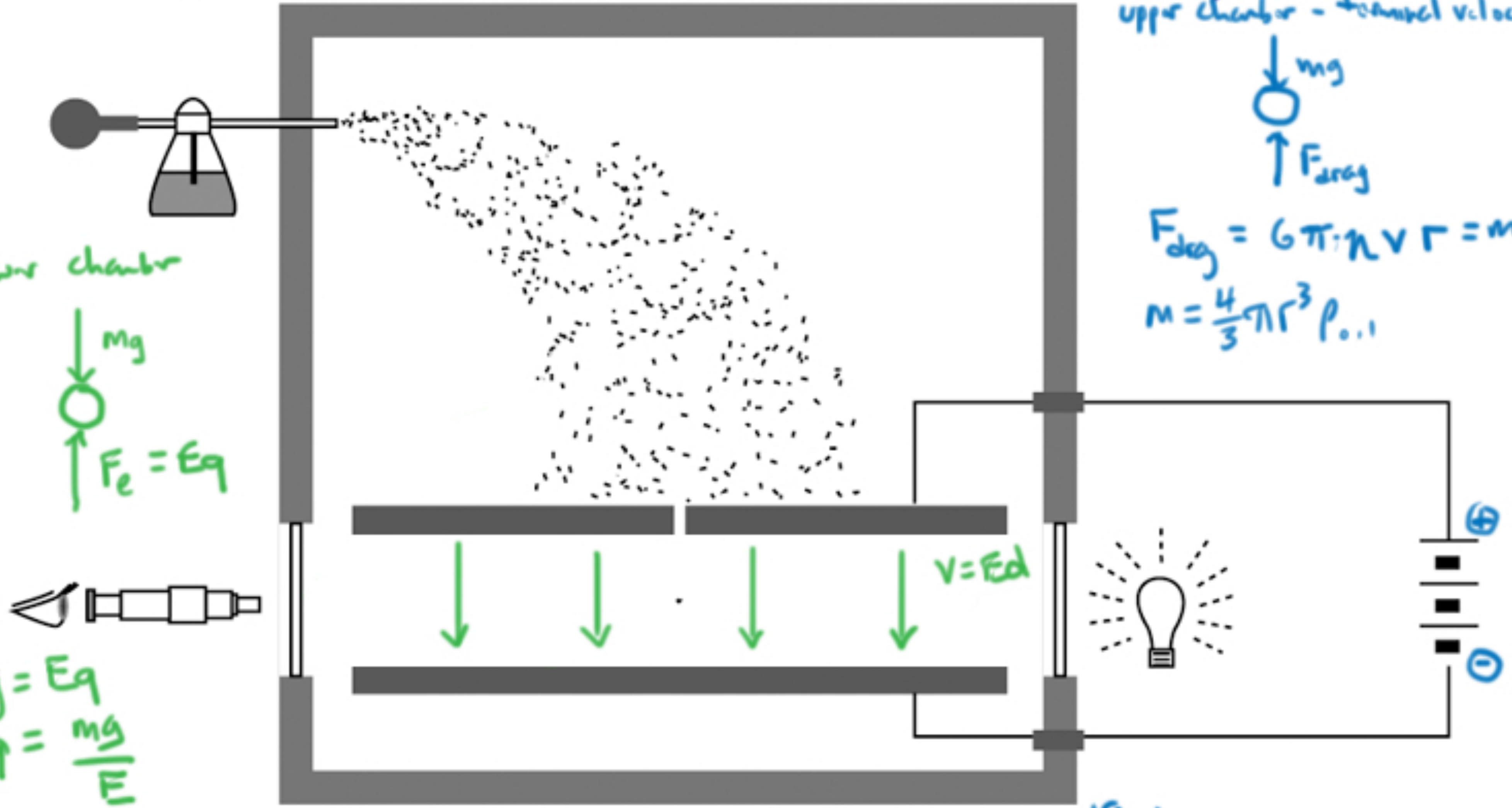
SDS coats proteins and gives them a uniform q/m ratio

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

mg

F_{drag}

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

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

lower chamber

mg

$F_e = Eq$

$$mg = Eq$$

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

q was always a simple multiple of -1.6×10^{-19} C = e

1 J = N · m

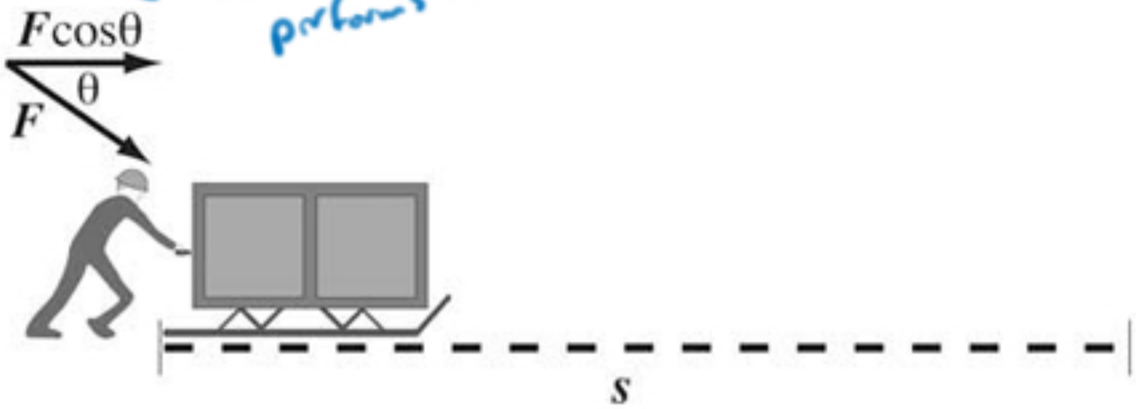
Mechanical Work

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

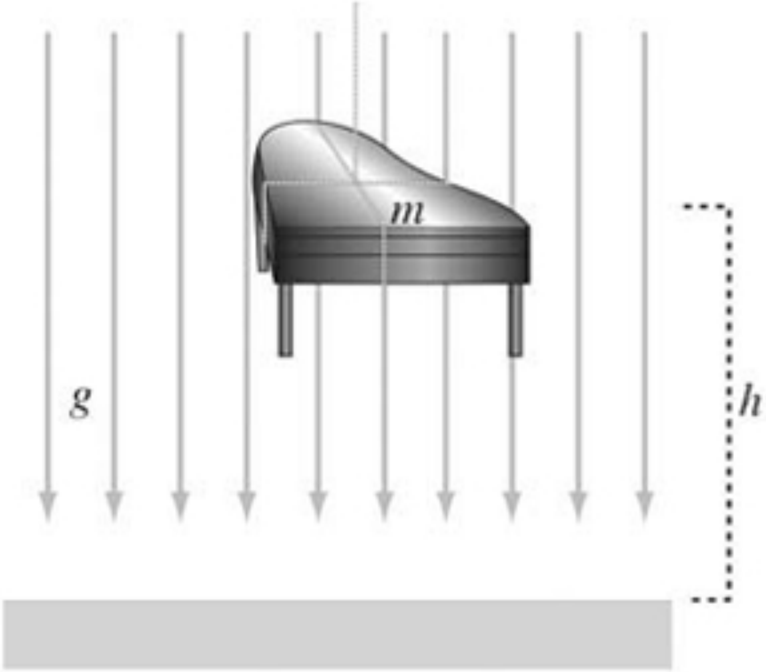
KE is the work invested in the motion or the work required to bring to rest.

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/s²)
h = height



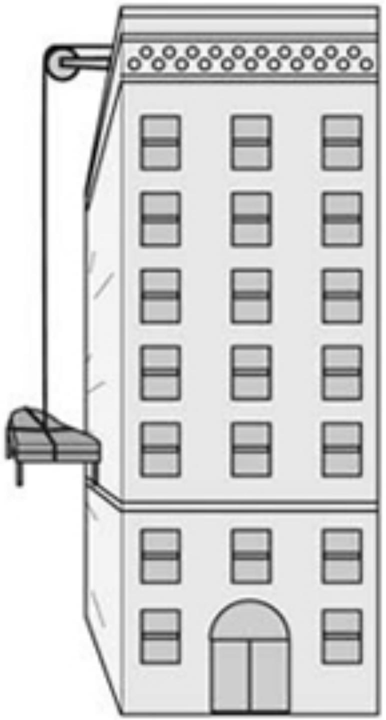
What is the minimum work required to raise a 500 kg piano from street level to a window at 20m elevation?

a. 10,000 J

b. 25000 J

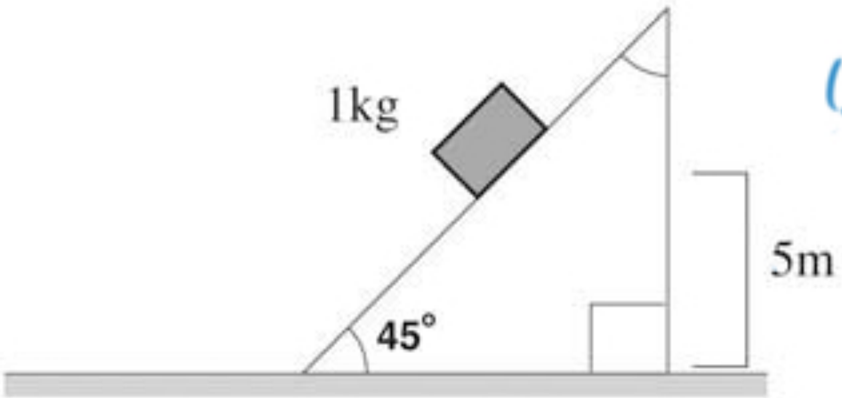
c. 100,000 J

d. 2.0 X 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



$PE_i = KE_f$

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

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

$v = 10\, m/s$

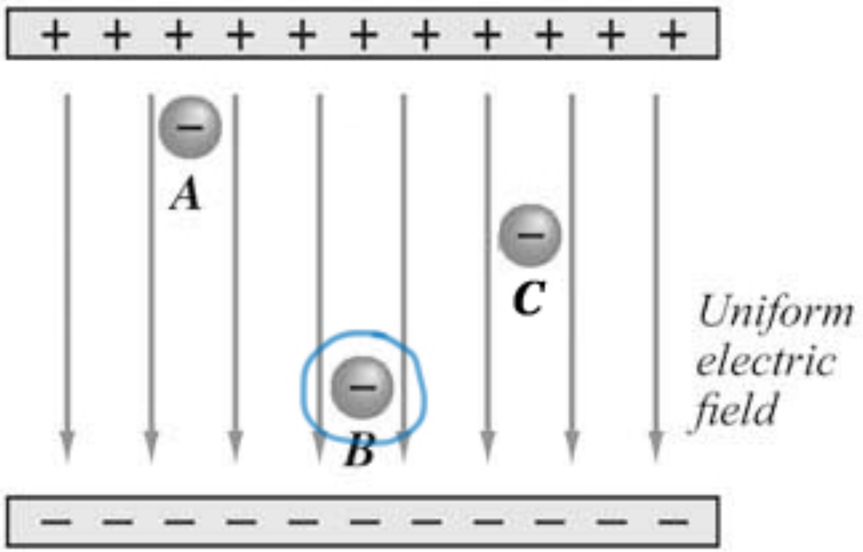
a. 1.7 m/s

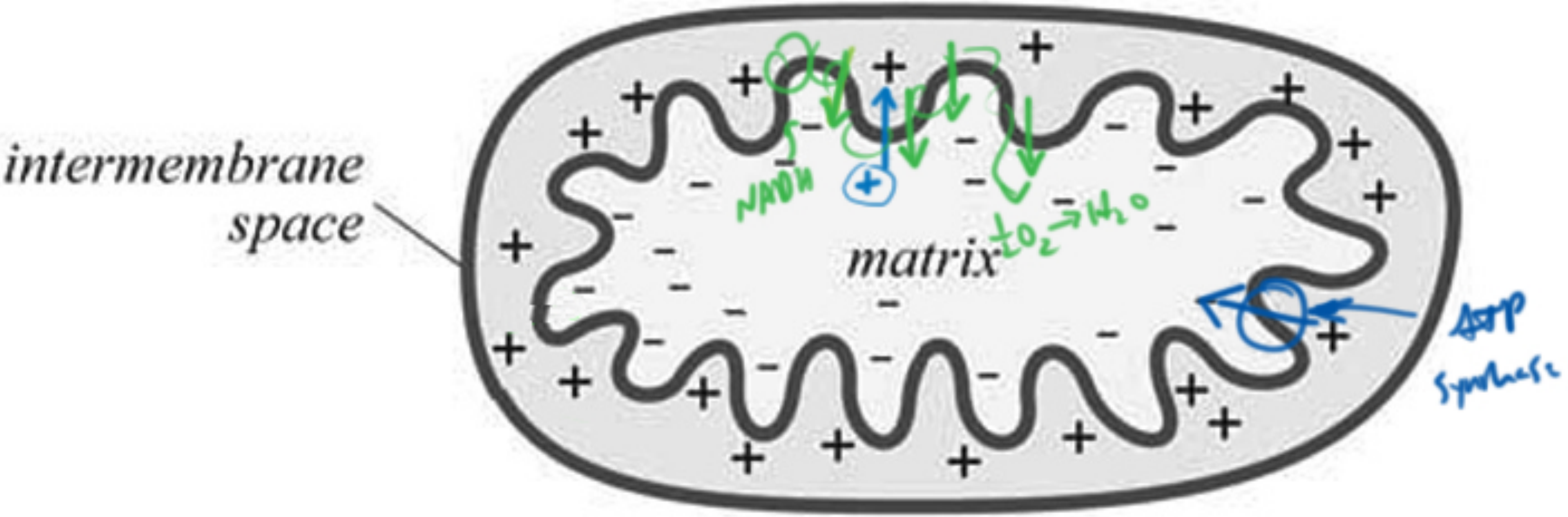
b. (5) ($\sqrt{2}$) m/s

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?



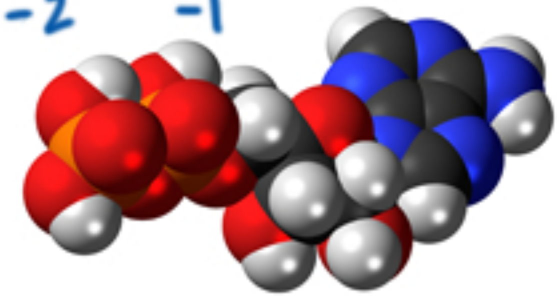

intermembrane
space
matrix
NADH
ATP
Synthase

P_i

-2

ADP

-2 -1

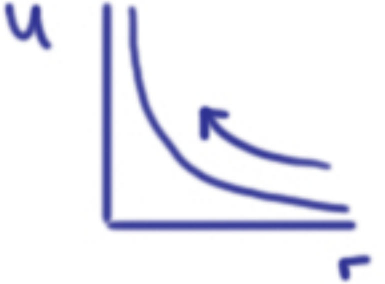


$$ADP + P_i \longrightarrow ATP$$

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

$\rightarrow$ (-2)

(-3) $\leftarrow$



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

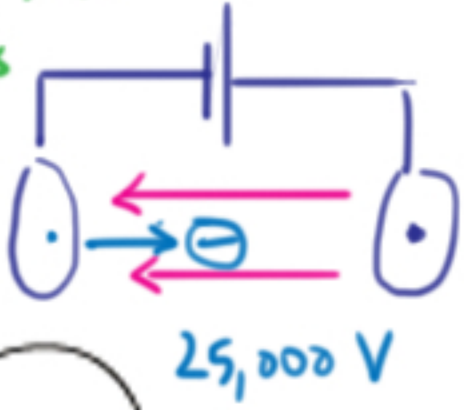
$e = 1.6 \times 10^{-19}$ C

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

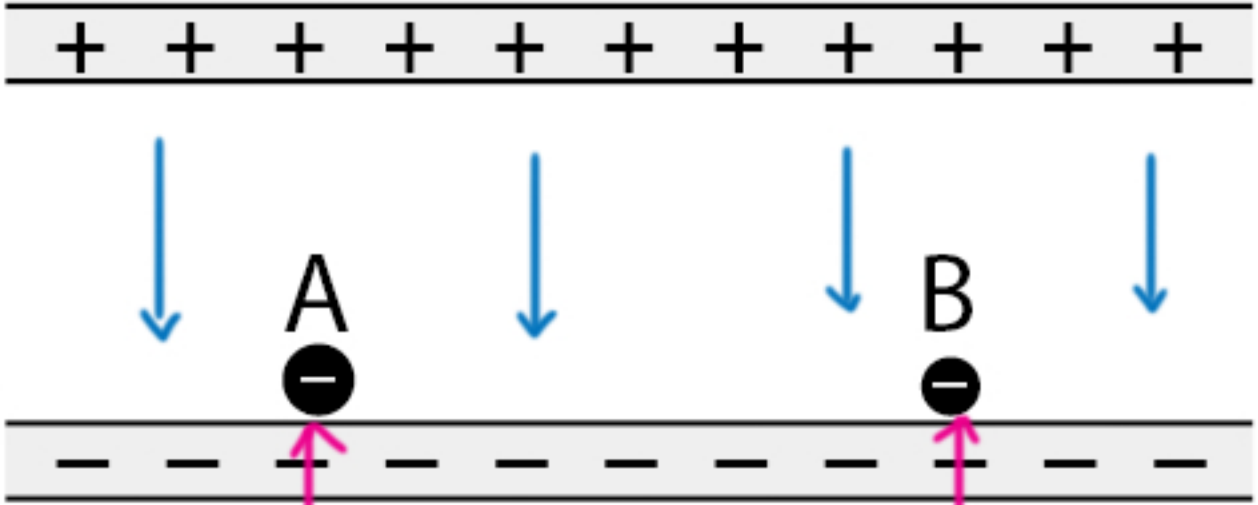
$q_A = q_B$ $m_A = 4 m_B$

$KE = \frac{1}{2} m v^2$

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

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

Four times the mass means half the speed.



F_e

$F = Eq$

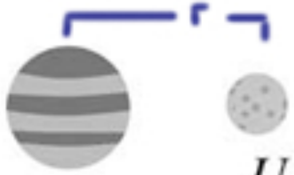
same force
same work

$\Delta KE = \text{work}$

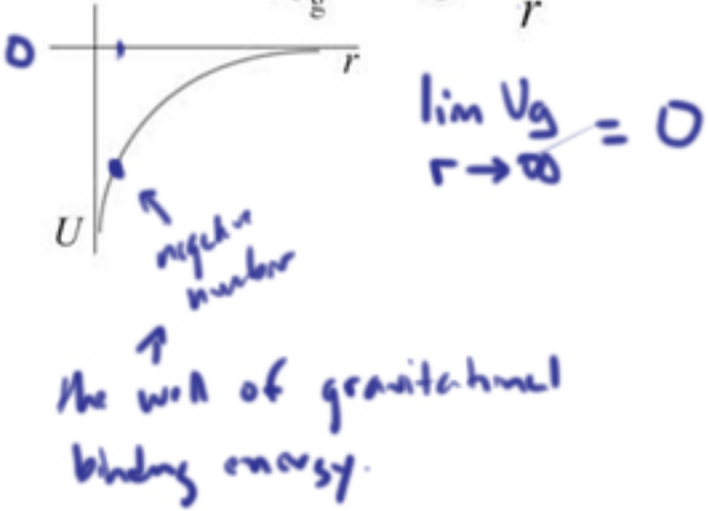
Which strikes with greater kinetic energy? or is it the same?

Gravitational and Electrostatic Potential Energy

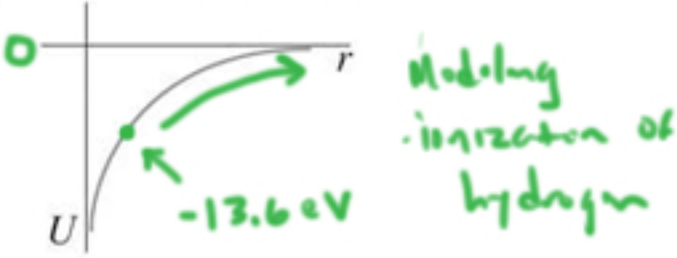
system of two masses or two point charges

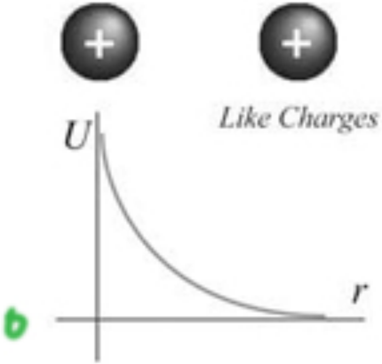


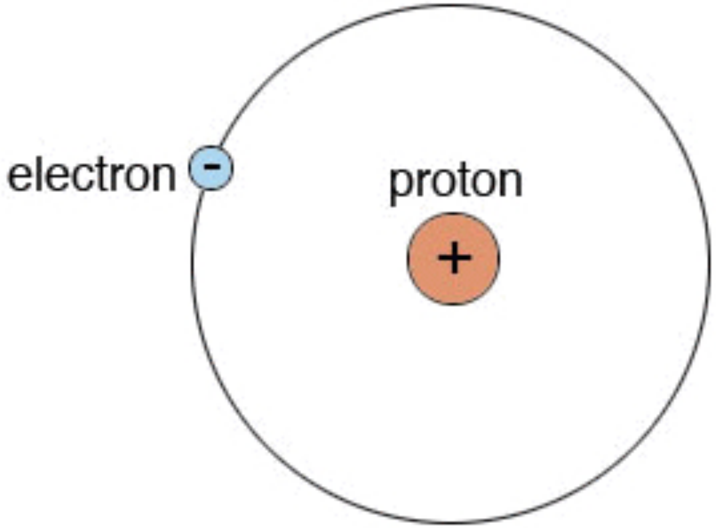
$$U_g = -G\frac{m_1 m_2}{r}$$



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







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.