AP® PHYSICS 2 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

$|\vec{F}_f| \leq \mu |\vec{F}_n|$

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

$\vec{p} = m\vec{v}$

$\Delta\vec{p} = \vec{F}\,\Delta t$

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

$\Delta E = W = F_{\parallel}d = Fd\cos\theta$

$P = \frac{\Delta E}{\Delta t}$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$

$\omega = \omega_0 + \alpha t$

$x = A\cos(\omega t) = A\cos(2\pi f t)$

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

$\tau = r_{\perp}F = rF\sin\theta$

$L = I\omega$

$\Delta L = \tau\,\Delta t$

$K = \frac{1}{2}I\omega^2$

$|\vec{F}_s| = k|\vec{x}|$

a = acceleration
A = amplitude
d = distance
E = energy
F = force
f = frequency
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed

$U_s = \frac{1}{2}kx^2$

$\Delta U_g = mg\,\Delta y$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

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

$\vec{g} = \frac{\vec{F}_g}{m}$

$U_G = -\frac{Gm_1 m_2}{r}$

ELECTRICITY AND MAGNETISM

$|\vec{F}_E| = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_2|}{r^2}$

$\vec{E} = \frac{\vec{F}_E}{q}$

$|\vec{E}| = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}$

$\Delta U_E = q\Delta V$

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

$|\vec{E}| = \left|\frac{\Delta V}{\Delta r}\right|$

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

$C = \kappa\varepsilon_0\frac{A}{d}$

$E = \frac{Q}{\varepsilon_0 A}$

$U_C = \frac{1}{2}Q\Delta V = \frac{1}{2}C(\Delta V)^2$

$I = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$P = I\,\Delta V$

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

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

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

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = separation
t = time
U = potential (stored) energy
V = electric potential
v = speed
κ = dielectric constant
ρ = resistivity
θ = angle
Φ = flux

$\vec{F}_M = q\vec{v} \times \vec{B}$

$|\vec{F}_M| = |q\vec{v}||\sin\theta||\vec{B}|$

$\vec{F}_M = I\vec{\ell} \times \vec{B}$

$|\vec{F}_M| = |I\vec{\ell}||\sin\theta||\vec{B}|$

$\Phi_B = \vec{B} \cdot \vec{A}$

$\Phi_B = |\vec{B}|\cos\theta|\vec{A}|$

$\mathcal{E} = -\frac{\Delta\Phi_B}{\Delta t}$

$\mathcal{E} = B\ell v$

AP® PHYSICS 2 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1\text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^8$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$	Universal gravitational constant, $G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}\text{ kg} = 931\ \text{MeV}/c^2$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J}\cdot\text{s} = 4.14 \times 10^{-15}\ \text{eV}\cdot\text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J}\cdot\text{m} = 1.24 \times 10^3\ \text{eV}\cdot\text{nm}$
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\varepsilon_0 = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}$
1 atmosphere pressure,	$1\text{ atm} = 1.0 \times 10^5\ \text{N/m}^2 = 1.0 \times 10^5\ \text{Pa}$

UNIT SYMBOLS	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.

II. In all situations, positive work is defined as work done <u>on</u> a system.

III. The direction of current is conventional current: the direction in which positive charge would drift.

IV. Assume all batteries and meters are ideal unless otherwise stated.

V. Assume edge effects for the electric field of a parallel plate capacitor unless otherwise stated.

VI. For any isolated electrically charged object, the electric potential is defined as zero at infinite distance from the charged object.

AP® PHYSICS 2 EQUATIONS

FLUID MECHANICS AND THERMAL PHYSICS

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

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

$P = P_0 + \rho g h$

$F_b = \rho V g$

$A_1 v_1 = A_2 v_2$

$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$

$\frac{Q}{\Delta t} = \frac{kA\,\Delta T}{L}$

$PV = nRT = Nk_BT$

$K = \frac{3}{2}k_BT$

$W = -P\Delta V$

$\Delta U = Q + W$

A = area
F = force
h = depth
k = thermal conductivity
K = kinetic energy
L = thickness
m = mass
n = number of moles
N = number of molecules
P = pressure
Q = energy transferred to a system by heating
T = temperature
t = time
U = internal energy
V = volume
v = speed
W = work done on a system
y = height
ρ = density

MODERN PHYSICS

$E = hf$

$K_{max} = hf - \phi$

$\lambda = \frac{h}{p}$

$E = mc^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

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

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

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

$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$

$|M| = \left|\frac{h_i}{h_o}\right| = \left|\frac{s_i}{s_o}\right|$

$\Delta L = m\lambda$

$d\sin\theta = m\lambda$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
s = distance
v = speed
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

Rectangular solid
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

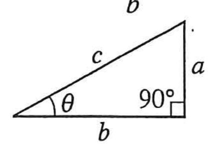
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

Right triangle
$c^2 = a^2 + b^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

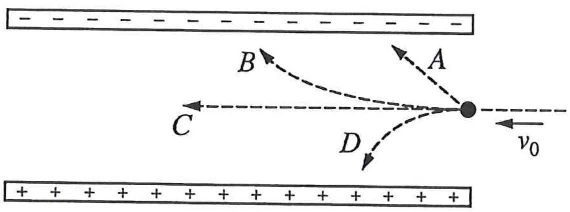
$\tan\theta = \frac{a}{b}$



PHYSICS 2
Section I
50 Questions
Time—90 minutes

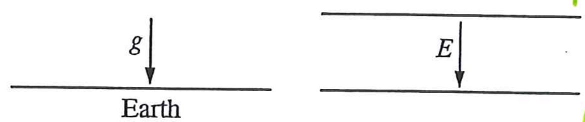
Note: To simplify calculations, you may use $g = 10 \text{ m/s}^2$ in all problems.

Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then enter the appropriate letter in the corresponding space on the answer sheet.



1. A proton is traveling to the left when it enters the space between two oppositely charged parallel plates, as shown above. Which of the four labeled paths will the proton take?

(A) *A*
(B) *B*
(C) *C*
(D) *D*



2. The figures above represent two fields. The figure on the left represents the uniform gravitational field very near Earth's surface. The figure on the right represents the uniform electric field *E* near the center of the region between very large parallel plates. Which of the following describes the shape of the isolines of potential for the gravitational field and the electric field in these regions?

(A) Isolines are straight, vertical lines for both the gravitational and electric fields.
(B) Isolines are straight, horizontal lines for both the gravitational and electric fields.
(C) Gravitational isolines are straight, while electric isolines are curved.
(D) Gravitational isolines are curved, while electric isolines are straight.

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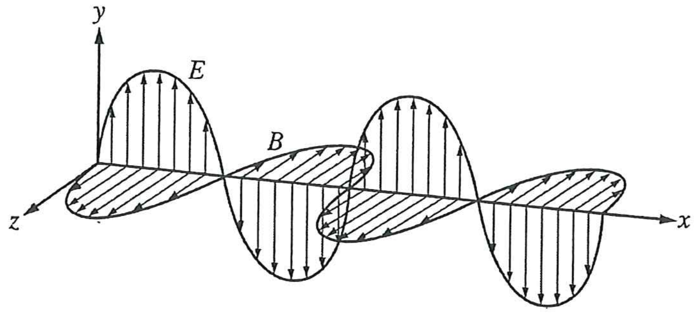

3. The figure above shows a model of an electromagnetic wave, where E is the electric field and B is the magnetic field. In what direction is the energy of the wave transmitted?

(A) Along the x-axis only
(B) Along the y-axis only
(C) Along the z-axis only
(D) In a direction that is at a nonzero angle to each of the axes

using wave theory, energy travels in direction of wave propagation

Using photon theory

$E = hf$ ← energy travels with photon

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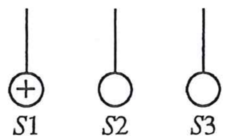


4. Three identical conducting spheres, $S1$, $S2$, and $S3$, are supported by insulating thread, as shown above. Initially, sphere $S1$ has a net positive charge and the other two spheres are uncharged. Spheres $S1$ and $S2$ are brought into contact and then separated. Next, spheres $S2$ and $S3$ are brought into contact and then separated. Which of the following shows the signs of the final net charges on the spheres?

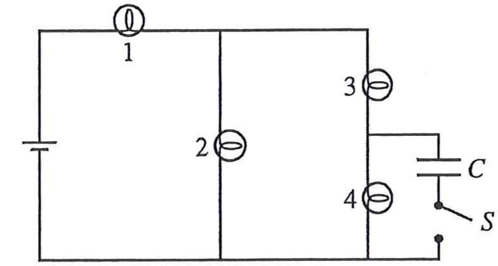
(A) ⊕ ⊕ ⊕

(B) ⊕ ○ ○

(C) ○ ○ ⊕

(D) ○ ⊕ ⊕

Questions 5-7 refer to the following material.



The circuit shown above contains four identical lightbulbs with constant resistance, a capacitor C, which is initially uncharged, and a switch S. The switch is initially open.

5. Which of the following correctly ranks the potential differences ΔV_1, ΔV_2, ΔV_3, and ΔV_4 across the bulbs while the switch is open?

(A) $\Delta V_1 = \Delta V_2 = \Delta V_3 = \Delta V_4$

(B) $\Delta V_1 > \Delta V_2 = \Delta V_3 = \Delta V_4$

(C) $\Delta V_1 > \Delta V_2 > \Delta V_3 = \Delta V_4$

(D) $\Delta V_1 > \Delta V_2 > \Delta V_3 > \Delta V_4$

6. Immediately after the switch is closed, the current in bulb 1 is I_a. What is the current in bulb 2 at that time?

(A) I_a

(B) $2I_a/3$

(C) $I_a/2$

(D) $I_a/3$

7. After the switch has been closed a long time, how does the brightness of bulb 4 compare with its brightness before the switch was closed?

(A) Bulb 4 is much dimmer and is only barely lit.

(B) Bulb 4 is slightly dimmer.

(C) Bulb 4 is the same brightness.

(D) Bulb 4 is slightly brighter.

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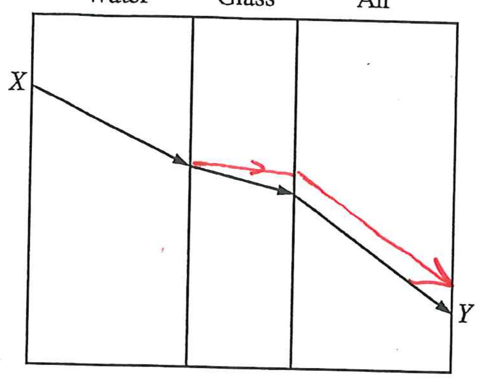


8. A light ray enters a layer of water at point X, passes through a layer of glass, and exits through a layer of air at point Y, as shown in the figure above. Where would the ray exit the layer of air if the glass was replaced with a material of higher index of refraction?

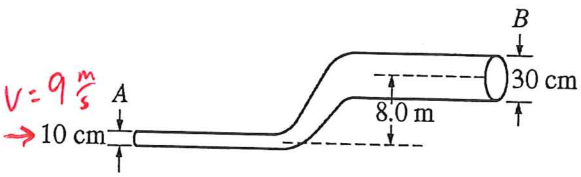
(A) At a point above point Y
(B) At a point below point Y
(C) At point Y
(D) The location cannot be determined without knowing how much higher the index of refraction of the new material is.

path will be parallel to original, But higher n bends glass ray closer to normal so above Y

9. Which of the following indicates the object distance s_o for which a spherical concave mirror of focal length f produces an upright image?

(A) $s_o < f$
(B) $s_o = f$
(C) $2f > s_o > f$
(D) $s_o > 2f$

Virtual $d_o < f$ (s_o)



Note: Figure not drawn to scale.

10. Water is flowing with a speed of 9.0 m/s through a pipe of diameter 10 cm. The pipe widens to 30 cm as it goes up an 8.0 m step, as shown in the figure above. If the pressure at point A is 2.0×10^5 Pa, what is the pressure at point B? (The density of water is 1.0×10^3 kg/m^3.)

(A) 1.2×10^5 Pa
(B) 1.6×10^5 Pa
(C) 2.4×10^5 Pa
(D) 3.2×10^5 Pa

Pascal

$A_A V_A = A_B V_B$

Bernoulli $\pi r_1^2 (9) = \pi r_2^2 v_B$

$10^2 \cdot 9 = 30^2 v_B$

$1 \text{ m/s} = v_B$

$P_A + \frac{1}{2}\rho v_A^2 + \rho g h_A = P_B + \frac{1}{2}\rho v_B^2 + \rho g h_B$

$2 \times 10^5 + \frac{1}{2}(1000)9^2 + 1000(0) = P + \frac{1}{2}(1000)1^2 + 1000(10)8$

$200000 + 40500 = P + 500 + 80000$

$1.6 \times 10^5 \text{ Pa} = P$

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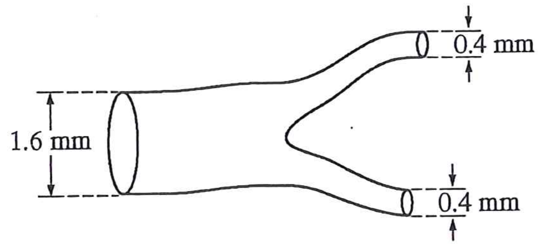


11. The figure above represents a portion of a blood vessel with circular cross sections. The segment on the left has diameter 1.6 mm, and each of the segments on the right has diameter 0.4 mm. Assume the blood can be treated as an ideal fluid. If blood enters the segment on the left with speed v, at what speed does the blood leave the segments on the right?

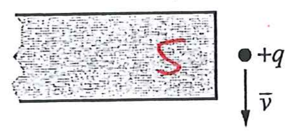
(A) $2v$
(B) $4v$
(C) $8v$
(D) $16v$

12. A slab of metal and a slab of wood are placed in a classroom and allowed to sit undisturbed for a long time. A student then places one hand on the metal and the other hand on the wood. Which of the following describes the student's perception of the temperatures of the slabs and their actual temperatures?

(A) The metal slab feels colder to the student because it is at a lower temperature.
(B) The metal slab feels colder to the student because it conducts thermal energy away from the student's hand faster, but the slabs have the same temperature.
(C) The metal slab feels warmer to the student because it conducts thermal energy to the student's hand faster, but the slabs have the same temperature.
(D) Both slabs feel the same to the student because they are at the same temperature.

13. When one end of a cold metal spoon is placed upright in a cup of hot cocoa, the other end eventually gets warmer. On the scale of the molecules of the spoon, which of the following is the primary explanation of this phenomenon?

(A) Higher-energy molecules will, on average, rise to the top.
(B) The hot molecules produce thermal radiation that is then absorbed by the colder molecules.
(C) Higher-energy molecules hit lower-energy molecules and, on average, tend to reduce the difference in temperature between the ends of the spoon.
(D) Thermal energy is a fluid that flows from high concentration (hot areas) to low concentration (cold areas).



14. An object with charge $+q$ passes to the right of one pole of a magnet and at a particular instant is moving with a velocity $\vec{v}$ toward the bottom of the page, as shown in the figure above. The force exerted on the object by the magnet at that instant is directed into the page. What is the direction of the force exerted on the magnet by the object?

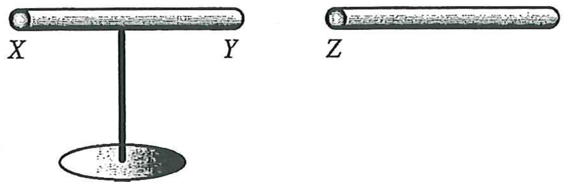
(A) Out of the page
(B) Toward the right
(C) Toward the top of the page
(D) No direction; the force is zero.

GO ON TO THE NEXT PAGE.

Wire	1	2	3	4	5
Current (A)	0.5	1.0	2.0	2.5	3.0

15. A student was given five wires of the same length and diameter. The student connected the wires to the same battery one by one and measured the current through each wire. The table above shows the data collected. Which of the following can be concluded from the data?

(A) The wires are ohmic.
(B) The wires are made of different materials.
(C) The resistance of the wires depends on their size and shape.
(D) The battery has internal resistance.



16. In the figure above, the initially uncharged insulating rod on the left is free to rotate on an insulating stand. End X is then rubbed with a piece of fur. End Z of a second insulating rod is also rubbed with fur and then brought near the first rod. As the second rod is moved around, it is found that end Y of the first rod is attracted to end Z, and end X is repelled. Which of the following correctly describes the signs of the charges on ends X and Y, if any?

	End X	End Y
(A)	Opposite Z's charge	Same as Z's charge
(B)	Opposite Z's charge	No net charge
(C)	Same as Z's charge	Opposite Z's charge
(D)	Same as Z's charge	No net charge

GO ON TO THE NEXT PAGE.

17. A student has a positively charged insulating rod and two initially uncharged conducting spheres, A and B, with insulated handles. Which of the following ordered sequences of actions could the student use to produce a net positive charge on sphere A ?

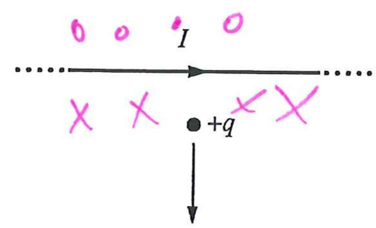
(A) Bring the rod near the right side of A. Touch B to the left side of A. Remove B and then remove the rod. *No, will make A neg*

(B) Bring the rod near the right side of A. Touch B to the left side of A. Remove the rod and then remove B. *No, will remain neutral*

(C) Bring the rod near the right side of B. Touch A to the left side of B. Remove B and then remove the rod. *Yes, electrons from A trans to B*

(D) Bring the rod near the right side of B. Touch A to the left side of B. Remove the rod and then remove B.

No makes neutral



18. The figure above shows a long conducting wire that lies in the plane of the page and carries an electric current I toward the right. At the instant shown, a positive point charge $+q$ is in the plane of the page and moving toward the bottom of the page. What is the direction of the magnetic force on the point charge at that instant?

(A) Into the page

(B) Out of the page

(C) Toward the right

(D) Toward the left

RHR

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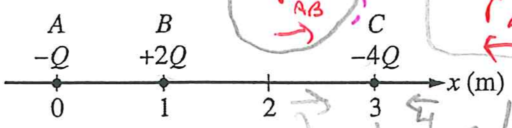
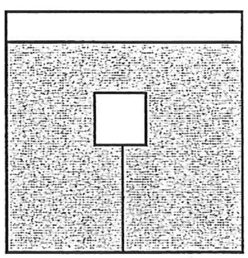


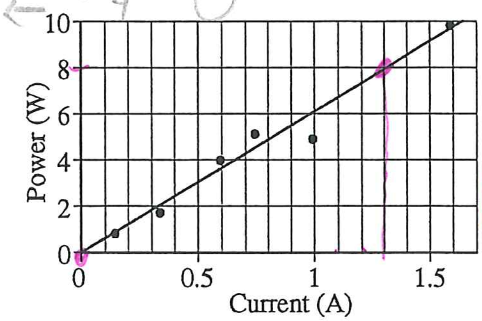
19. The figure above shows three point charges located on an x-axis. Which of the following ranks the magnitude of the net electric force, F, on each point charge due to the other charges?

(A) $F_A = F_C > F_B$
(B) $F_B > F_C = F_A$
(C) $F_A = F_B > F_C$
(D) $F_A > F_C > F_B$



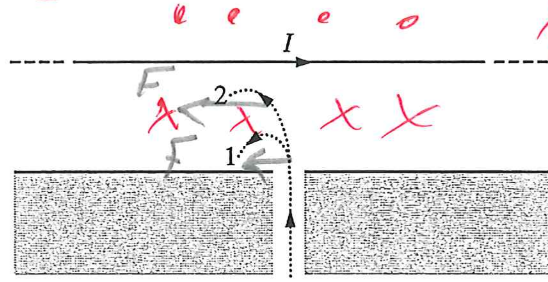
20. A block is submerged in a container of liquid and held under the surface of the liquid by a string connected to the bottom of the container, as shown in the figure above. The tension in the string is not zero. How does the buoyant force F_B exerted by the liquid on the block compare to the block's weight w ?

(A) $F_B < w$
(B) $F_B = w$
(C) $F_B > w$
(D) Either $F_B < w$ or $F_B > w$, depending on the density of the liquid.



21. A variable resistor is connected to a battery of unknown potential difference. The power dissipated by the resistor and the current through the resistor are measured. The figure above shows a graph of the data and a best-fit line for the data. The potential difference provided by the battery is most nearly

(A) 0.3 V
(B) 3.0 V
(C) 5.0 V
(D) 6.0 V



Note: Figure not drawn to scale.

22. A scientist is studying the radioactive decay of an element and wants to determine the sign of some of the particles emitted. The scientist lets a beam of the particles, all with the same speed, pass through an opening in a shield and enter the field created by a wire carrying a constant current. Paths 1 and 2 represent the observed paths of the particles. Based on the paths, which of the following could be the types of particles?

	Path 1 Particle	Path 2 Particle
(A)	Electron	Alpha
(B)	Alpha	Electron
(C)	Positron	Alpha
(D)	Alpha	Positron

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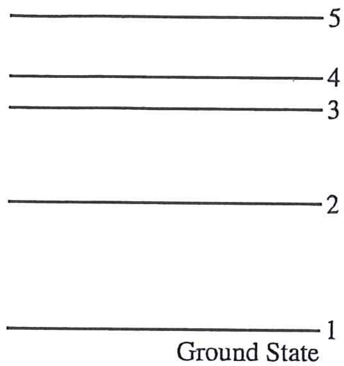


23. The energy states for an electron in a hypothetical atom are represented above. A cold sample of gas of such atoms is illuminated by a brief flash of light with a continuous spectrum. The atoms are then observed to emit light with discrete wavelengths. Which of the following transitions produces the longest wavelength light?

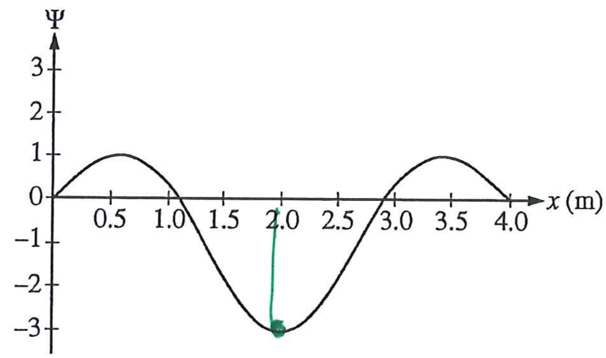
(A) 5 to 4
(B) 4 to 3
(C) 3 to 2
(D) 2 to 1

low energy

24. A nucleus of ${}^{238}_{92}\text{U}$ undergoes a series of decays in which it emits eight ${}^{4}_{2}\text{He}$ nuclei and some β^- particles to produce the nucleus ${}^{206}_{82}\text{Pb}$. How many β^- particles are emitted in the process?

(A) 10
(B) 8
(C) 6
(D) 5

$238-32=206$
$92-16=76$
must increase charge from $76 \to 82$, emit 6 β's



25. The graph above shows the wave function $\Psi(x)$ of a particle moving in the region $0 < x < 4$ m. At which of the following positions is the probability of finding the particle greatest?

(A) 0.7 m
(B) 2.0 m
(C) 2.5 m
(D) 4.0 m

$P(\psi) \propto \psi^2$

$$n + {}^{235}_{92}\text{U} \rightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3n$$

26. Which of the following expressions, where m represents the mass of a particle, equals the energy released in the nuclear reaction represented above?

(A) $(m_{Ba} + m_{Kr} + m_U - 3m_n)c^2$
(B) $(m_{Ba} + m_{Kr} - m_U - 2m_n)c^2$
(C) $(m_U - m_{Ba} - m_{Kr} - 3m_n)c^2$
(D) $(m_U - m_{Ba} - m_{Kr} - 2m_n)c^2$

energy in, energy out + mc^2

$m_n + m_U - m_{Ba} - m_{Kr} - 3m_n = m$

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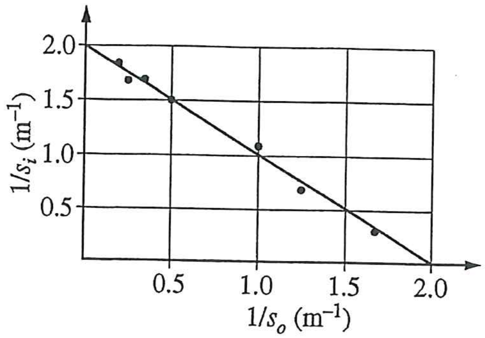
Questions 27-28 refer to the following material.



A group of students collected data using a lens. They varied the distance s_o of an object from the lens and measured the image distance s_i. The figure above is their graph of the inverse of the image distance as a function of the inverse of the object distance.

27. The focal length of the lens is approximately

(A) 0.5 m
(B) 1.0 m
(C) 2.0 m
(D) 4.0 m

28. What is the magnitude of the image's magnification when the object is placed 2 m from the lens?

(A) 1/3
(B) 1
(C) 3
(D) The magnification is undefined because the image is an infinite distance from the lens.

29. A partially evacuated vertical cylindrical container is covered by a circular lid that makes an airtight seal. The pressure in the room surrounding the container is $1.01 \times 10^5\ \text{N/m}^2$, and the pressure inside the container is $0.41 \times 10^5\ \text{N/m}^2$. The lid has radius 0.20 m and weight 200 N. The minimum upward applied force required to lift the lid is most nearly

(A) 7.5×10^3 N
(B) 7.7×10^3 N
(C) 1.3×10^4 N
(D) 1.8×10^4 N

30. A sealed container of air has been sitting on a table in a dark room for a very long time. The room is always kept at a constant temperature. Which of the following best describes what will happen to the speeds and the average kinetic energy of the molecules of the air in the container as the container continues to sit on the table?

(A) Each molecule will continue to move at constant speed, keeping the average kinetic energy of the molecules constant.
(B) Some molecules will speed up and others will slow down, keeping the average kinetic energy of the molecules constant.
(C) The molecules will gradually slow down, decreasing their average kinetic energy.
(D) The molecules will gradually speed up, increasing their average kinetic energy.

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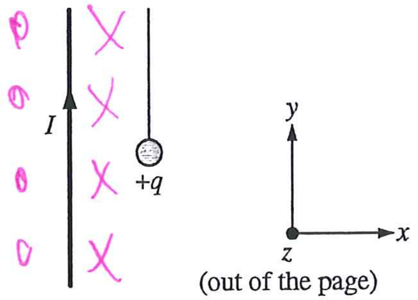

31. The figure above shows a long, straight wire that has a steady current I in the $+y$-direction. A small object with charge $+q$ hangs from a thread near the wire. A student wants to investigate the magnetic force on the object due to the current but is not able to observe or measure changes in the tension in the string. Of the following actions that the student can take, which will allow the student to observe a reaction of the object due to the magnetic force on it?

(A) Holding the object motionless ← Nope, no V

(B) Moving the object in a circle that is centered on the wire and in the x-z plane

(C) Moving the object in the $-x$-direction

(D) Moving the object in the $+y$-direction

$F_B = qvB$

Would affect tension but we can't!

Nope that is ∥ to B and V must be ⊥ B

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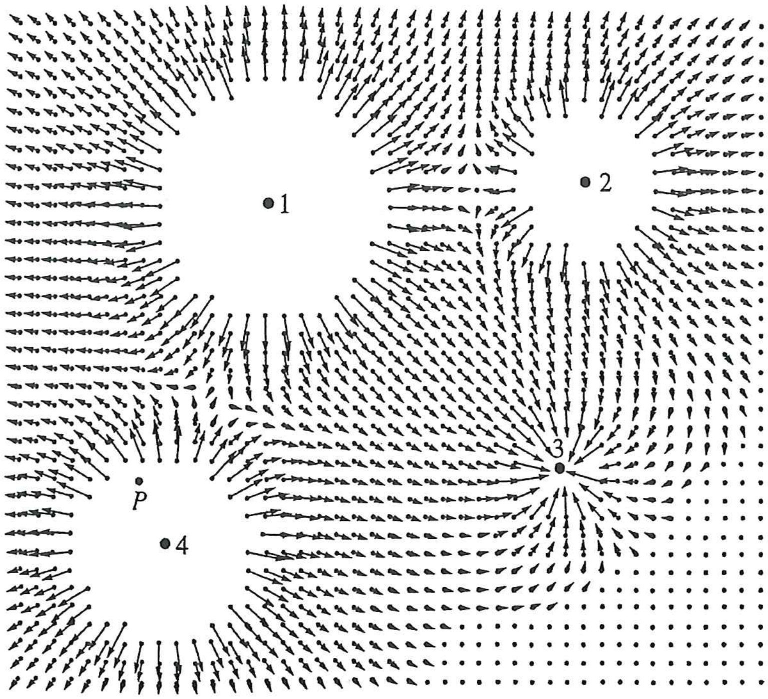
Questions 32-33 refer to the following material.



The figure above shows the electric field in a region surrounding four charged particles, labeled 1, 2, 3, and 4, that are held in place. (Vectors with very large magnitude are not shown.)

32. A small positive test charge is held at point P. Which of the following is closest to the direction of the force exerted on the test charge?

(A) 

(B) 

(C) 

(D) 

33. Which of the following indicates the particles with charges of the greatest and the least magnitude?

	Greatest	Least
(A)	4	2
(B)	3	1
(C)	2	4
(D)	1	3

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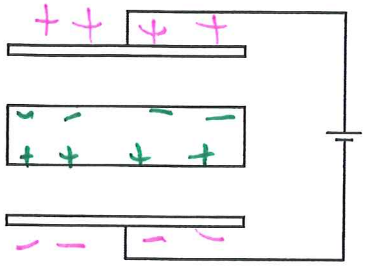
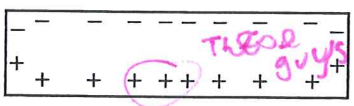
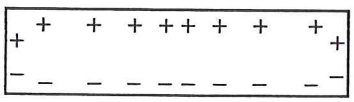
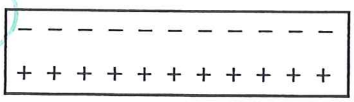


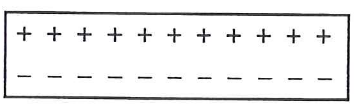
34. A parallel-plate capacitor is connected to a battery. A thick metal plate is located between the plates of the capacitor, as shown above. Which of the following best shows the distribution of charge on the thick plate?

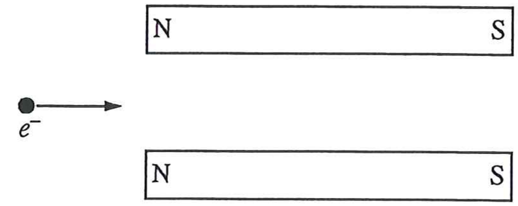
(A) 

These guys will move!

(B) 

(C) 

(D) 



35. At the instant shown above, an electron is moving to the right along a straight line midway between two identical bar magnets. Which of the following describes the path of the electron as it continues to move?

(A) It remains on the straight line and passes completely between the magnets.
(B) It curves upward and strikes the top magnet.
(C) It curves downward and reverses direction before it enters the space between the magnets.
(D) It stops and reverses direction, then moves to the left along the same straight line.

should be zero B
$F_B = qvB = 0$

36. Which of the following procedures can a student follow to give a metallic sphere a positive charge by induction?

(A) Touching the sphere with a positively charged rod
(B) Placing a negatively charged rod near the sphere
(C) Placing a positively charged rod near the sphere, grounding the sphere, and then removing the connection to ground
(D) Placing a negatively charged rod near the sphere, grounding the sphere, and then removing the connection to ground

No touching with charged object

repels e^- in sphere which go to ground

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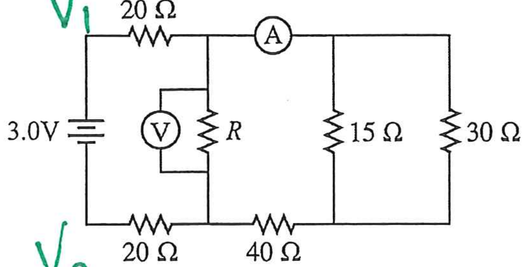
Questions 37-38 refer to the following material.



In the circuit shown above, the current through the ammeter is 20 mA and the voltmeter indicates 1.0 V.

37. What is the current through the 40 Ω resistor?

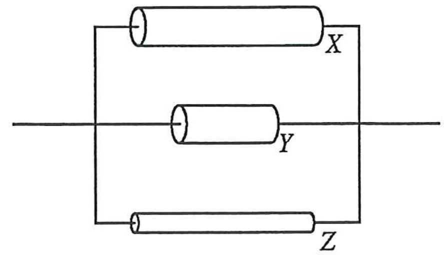
(A) 7.5 mA
(B) 10 mA
(C) 20 mA
(D) 40 mA

same I returns to source

38. The resistance of resistor R is most nearly

(A) 50 Ω
(B) 33 Ω
(C) 20 Ω
(D) 14 Ω

$V_1 = V_3$
$V_s = V_1 + V_3 + V_R$
$3 = V_1 + V_1 + 1$
$V_1 = 1V$
Since V_1 & V_R & V_3 are equal then $R = R_1$



39. The figure above represents a section of a circuit containing three resistors, X, Y, and Z, of different sizes but made of the same material. Which of the following correctly ranks the current in the resistors?

(A) $I_Z > I_X > I_Y$
(B) $I_Z = I_X > I_Y$
(C) $I_Y = I_X = I_Z$
(D) $I_Y > I_X > I_Z$

const ↓ $R = \frac{\rho l}{A}$ ← short, A ← fat
make R small makes I big

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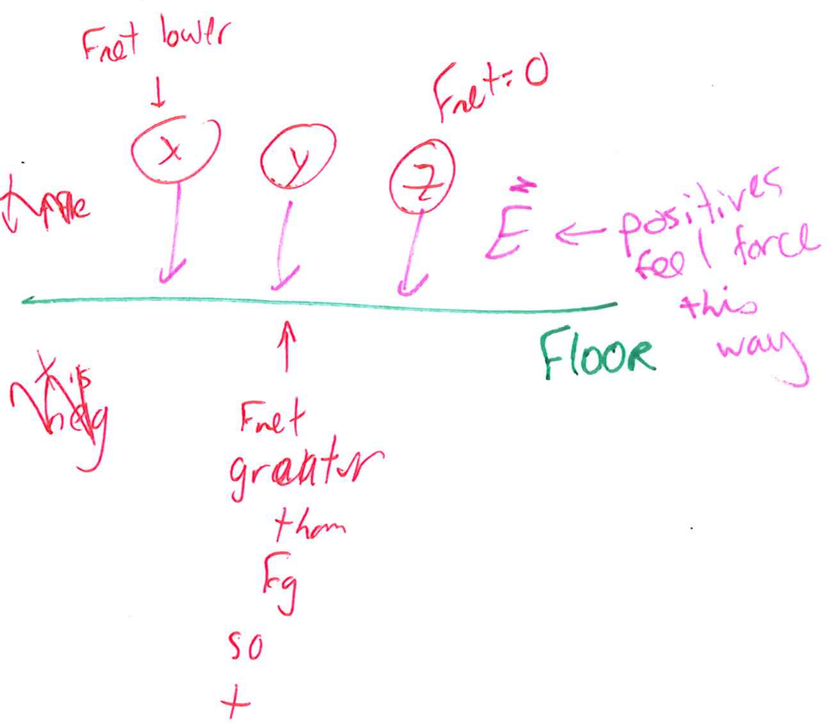
40. Three identical, small cork spheres are released from rest in a uniform electric field directed downward toward the floor. Sphere X is uncharged, but spheres Y and Z are charged. Sphere Z remains suspended in the field. Spheres X and Y fall downward, but sphere X takes a longer time to reach the floor. What are the signs of the charges on spheres Y and Z?

	Sphere Y	Sphere Z
(A)	Negative	Negative
(B)	Negative	Positive
(C)	Positive	Positive
(D)	Positive	Negative



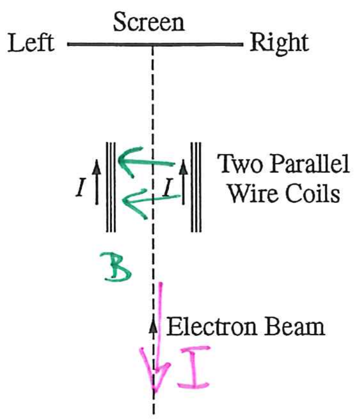
41. Two charged objects are held at a distance d apart. Their mutual gravitational force is equal to their mutual electrostatic force. Which of the following must be true of the charges and masses of the objects, if charge is expressed in C and mass is expressed in kg?

(A) The magnitude of the product of the charges must equal the magnitude of the product of the masses.
(B) The magnitude of the product of the charges must be much less than the magnitude of the product of the masses.
(C) The magnitude of the product of the charges must be much greater than the magnitude of the product of the masses.
(D) The charges must be equal and the masses must be equal.

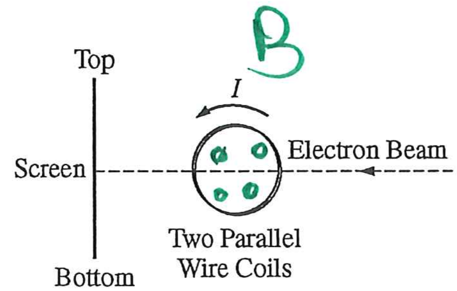
$F_e = F_g$

$\frac{kQQ}{r^2} = \frac{Gmm}{r^2}$

$k \gg G$



Top View



Side View

42. A beam of electrons travels between two parallel wire coils, as shown in the figures above. When the coils carry no current, the electron beam is undeflected and hits the center of the screen, as indicated by the dashed line. When a constant current I in the indicated direction is created in the coils, the electron beam is deflected toward which edge of the screen?

(A) The top
(B) The bottom
(C) The left
(D) None; it is not deflected.

RHR

43. An absorption spectrum, observed for light traveling through interstellar gases, appears as a broad spectrum of light with isolated dark lines at frequencies characteristic of the molecules in the gases. Which of the following is primarily responsible for the location of the dark absorption lines in the spectrum?

(A) The characteristic velocities of the molecules in the gas
(B) The transition of electrons between discrete energy states within the gas molecules
(C) The percent of the gas molecules that were ionized by absorption of energy
(D) The fluctuations in density of molecules present in the interstellar gas cloud

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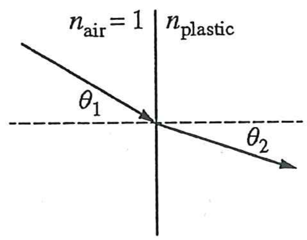
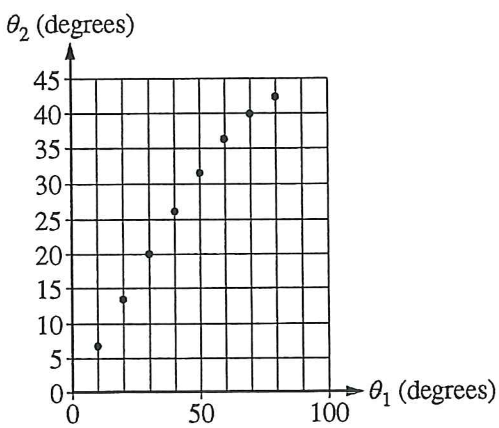
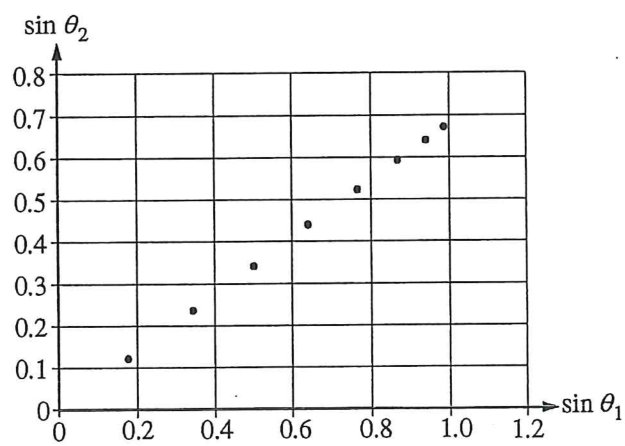


Figure 1

44. A student performs an experiment to determine the index of refraction of a plastic block. The student shines a laser beam from air ($n_{air} = 1$) into a piece of plastic ($n_{plastic}$) at an angle of incidence θ_1 and measures the angle of refraction θ_2, as shown in Figure 1 above. Measurements are taken as θ_1 is increased. From the data the student produces the two graphs shown below.



Graph 1



Graph 2

Which of the following is equal to the index of refraction of the plastic block?

(A) The slope of the best-fit line for graph 1
(B) The slope of the best-fit line for graph 2
(C) The inverse of the slope of the best-fit line for graph 1
(D) The inverse of the slope of the best-fit line for graph 2

$n_a \sin\theta_1 = n_2 \sin\theta_2$

$\frac{1 \sin\theta_1}{\sin\theta_2} = n_2$

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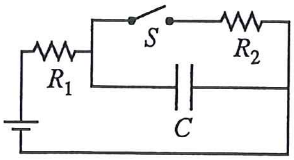


45. In the circuit represented above, two resistors (R_1 and R_2), a capacitor C, and an open switch S are connected to a battery. The circuit reaches equilibrium. The switch is then closed, and the circuit is allowed to come to a new equilibrium. Which of the following is a true statement about the energy stored in the capacitor after the switch is closed compared with the energy stored in the capacitor before the switch is closed?

(A) The energy is greater.
(B) The energy is less.
(C) The energy is the same.
(D) The energy cannot be determined without knowing the resistances of the resistors.

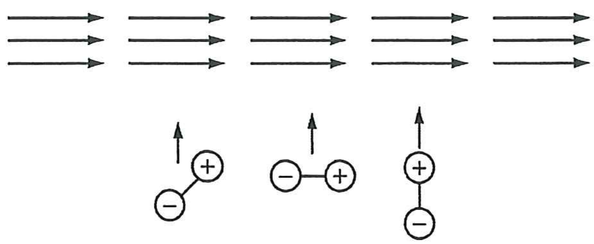
$V_c = V_{source}$

capacitor fully charged

V_c still $= V_s$

$U = \frac{1}{2}CV^2$ still

Directions: For each of the questions or incomplete statements below, two of the suggested answers will be correct. For each of these questions, you must select both correct choices to earn credit. No partial credit will be earned if only one correct choice is selected. Select the two that are best in each case and then enter both of the appropriate letters in the corresponding space on the answer sheet.



46. The figure above represents part of a student's experiment in which polar molecules are moving toward the top of the page at high speed. The molecules are modeled as atoms with a positive and a negative charge connected by a molecular bond. The molecules pass through a narrow region of uniform electric field directed to the right. Since the molecules have no net charge, the student expects that the field will have no effect on them and is puzzled to find that the molecules have a higher average energy when they emerge on the other side of the field. Which of the following could explain the student's observation? Select two answers.

(A) Since some molecules enter the field aligned at an angle to the field—like the molecule on the left—the field exerts a torque on them, which causes them to rotate and gives them rotational kinetic energy.

(B) Since the molecules are polar, they behave as if they have a net charge. The field exerts a net force on them that does work and gives them linear kinetic energy.

(C) Since some molecules enter the field aligned parallel to its direction—like the molecule in the middle—the field exerts forces in opposite directions on the two atoms, which stretches the molecular bonds and gives the molecules internal energy.

(D) Since some molecules enter the field aligned perpendicular to its direction—like the molecule on the right—the field exerts forces in opposite directions on the two atoms. The force on the positive charge is greater, so the net force does work and gives them linear kinetic energy.

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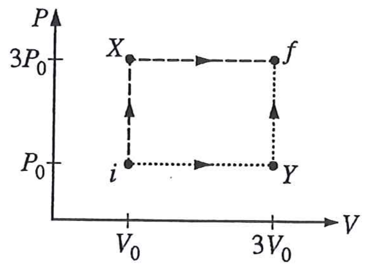
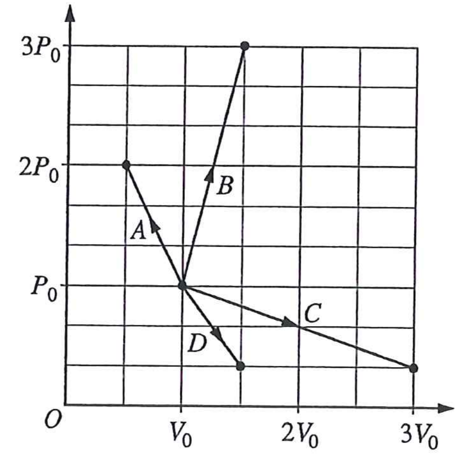


47. A sample of an ideal gas can be taken from state i to state f via two processes, as shown in the above graph of pressure P versus volume V. In one process the gas goes through state X, and in the other process the gas goes through state Y. Which of the following will be the same for both processes? Select two answers.

(A) The change in the internal energy of the gas
(B) The temperature of the gas at the end of the process
(C) The thermal energy transferred to the gas by heating
(D) The work done on the gas



48. Identical samples of gas initially have pressure P_0, volume V_0, and temperature T_0. In some experiments, students take samples through each of the processes shown in the graph above. The final temperature is equal to the initial temperature for which of the processes? Select two answers.

(A) A
(B) B
(C) C
(D) D

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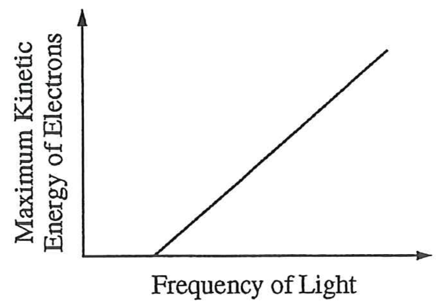
49. A beam of electrons is moving at a speed of 6×10^6 m/s. If the beam is incident on each of the following objects, for which of the objects will diffraction be observed? Select two answers.

(A) A human hair (diameter about 10^{-5} m)
(B) A metal crystal (interatomic spacing about 10^{-10} m)
(C) A nanometer-width slit (size about 10^{-9} m)
(D) A narrow paper strip (width about 10^{-3} m)

diffraction best when obj $\approx \lambda$

$p = mv = \frac{h}{\lambda}$ $\lambda = \frac{h}{mv}$

$\lambda = 1.2 \times 10^{-10}$ m



50. The graph above shows the maximum kinetic energy of electrons released in the photoelectric effect as a function of the frequency of the incident light. This graph is often used as evidence of the particle nature of light. The graph supports which of the following statements? Select two answers.

(A) The number of photoelectrons increases as the frequency increases. ← Nope E_k increases w/f
(B) There is a threshold frequency below which no photoemission occurs. ← yep
(C) The energy of photoelectrons depends on the energy of the incoming light. ← yep since $E = hf$
(D) The intensity of the incoming light determines whether photoemission occurs. ← Nope intensity ctrls #e^-

$hf = W + E_k$

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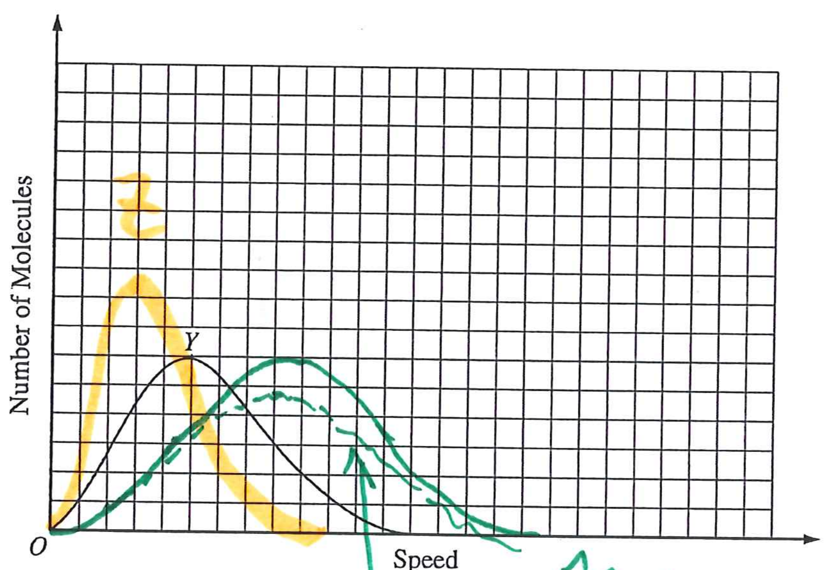
PHYSICS 2
Section II
4 Questions
Time—90 minutes

Directions: Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Show your work for each part in the space provided after that part.

$E_k = \frac{3}{2}kT$ for one molecule, total $E = n\left(\frac{3}{2}kT\right)$

1. (10 points, suggested time 20 minutes)
Three samples of a gas, X, Y, and Z, are prepared. Each sample contains the same number of molecules, but the samples are at different temperatures. The temperature of sample X is T_X, the temperature of sample Y is lower than that of sample X, and the temperature of sample Z is lower than that of sample Y $(T_X > T_Y > T_Z)$.

(a) The graph below shows the distribution of the speeds of the molecules in sample Y. On the graph, sketch and label possible distributions for sample X and sample Z.



Since $\frac{3}{2}kT = \frac{1}{2}mv^2$

$T_X > T_Y$

$\therefore$ $V_{x\,ave} > V_{y\,ave}$

$V_Z < V_Y$

Better

X ← needs lower peak

Note # molecules is NOT total molecules, its the # of molecules AT A PARTICULAR SPEED

The three samples with initial temperatures $T_X > T_Y > T_Z$ are placed in thermal contact, with sample Z in the middle, as shown below, and the samples are insulated from their surroundings. The samples can exchange thermal energy but not gas molecules. The samples eventually reach equilibrium, with a final temperature greater than T_Y.

X	Z	Y

(b) In a few sentences, describe the change over time in the average kinetic energy of the molecules of each sample, from initial contact until they reach equilibrium. Explain how these changes relate to the energy flow between the pairs of samples that are in contact.

Sample X Ave E_k drops as energy has net transfer out of X, slowing their speed

Sample Y Ave E_k increases as $T_f > T_y$ but for this to occur Energy must transfer $X \to Z \to Y$ as net initial flow will be $Y \to Z$ so, loss, then gain

Sample Z Ave E_k increases throughout

(c) Indicate whether the net entropy of sample X increases, decreases, or remains the same as a result of the process of reaching equilibrium.

____ Increases __X__ Decreases ____ Remains the same

Justify your answer at the microscopic level.

$\Delta S = \frac{Q}{T_{ave}}$ since Q neg due to loss

ΔS_X neg as $T_f < T_0$

But other bodies will have ΔS more positive

(d) For the three-sample system, indicate whether the entropy of the system increases, decreases, or remains the same.

__✓__ Increases ____ Decreases ____ Remains the same

Justify your answer.

ΔS will be greater + for Z & Y whose Temps rise as T_{ave} cold will be less than T_{ave} hot ∴ as Q = same ΔS + will exceed loss of entropy of hot body

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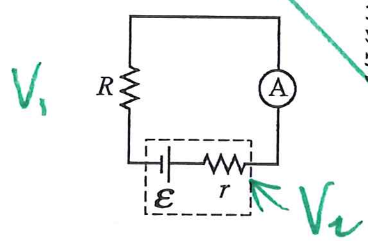
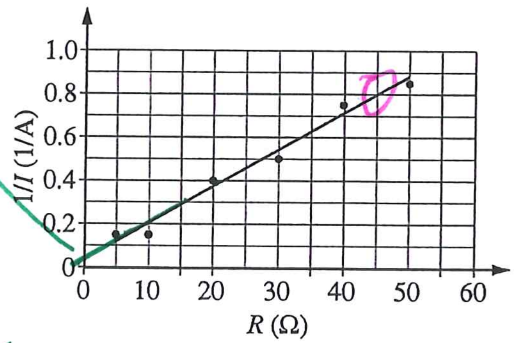
y intercept: 0.05A' or I = 20A





2. (12 points, suggested time 25 minutes)
Students are given some resistors with various resistances, a battery with internal resistance, and an ammeter. They are asked to determine the emf $\mathcal{E}$ and internal resistance r of the battery using just this equipment. Working with the circuit shown above, they insert each resistor into the circuit and measure the current I in the circuit each time they insert a resistor. From their data, the students generate a graph of $1/I$ as a function of the resistance R of each resistor, as shown above.

(a)

i. Write an algebraic equation describing the circuit that includes $\mathcal{E}$, R, r, and I.

KVL

$\mathcal{E} = V_1 + V_2$ $\quad\quad$ $\mathcal{E} = I(R + r)$

* $\mathcal{E} = IR_1 + Ir$ $\quad\quad$ $\mathcal{E} = I(R_{TOTAL})$ ← Not asked for but useful

ii. Use your equation and the graph to calculate the emf of the battery and the internal resistance of the battery.

Slope $= \frac{\frac{1}{I}}{R_1} = \frac{1}{I} \times \frac{1}{R_1} = \frac{1}{V_1}$ ∴ inverse of slope $= V_1$

$V_1 = IR_1$

so

$\frac{1}{V_1} = \frac{1}{I} \times \frac{1}{R_1}$

When $R_1 = 0$ $R_{TOT} = r$

and $\mathcal{E} = Ir$

so on graph where $R = 0$

gives $\mathcal{E} = \frac{1}{.05} r$ $\quad$ $\mathcal{E} = 20r$

$\frac{\mathcal{E}}{I} = R + r$

$\frac{\mathcal{E}}{I} - R = r$ use point on graph indicated

$\mathcal{E} = 60V$

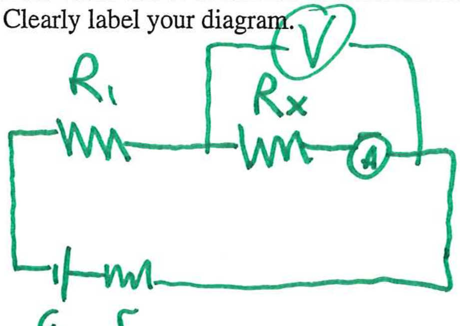
$\frac{\mathcal{E}}{10/8} - 45 = r$ ∴ $r = \frac{20r}{10/8} - 45$

$r = 16r - 45$ $\quad$ $r = 3\Omega$

The students are now given a voltmeter and a new resistor X to use with the resistors, battery, and ammeter they already have. They are asked to determine whether resistor X is ohmic. ← constant R

(b)

i. Using standard symbols for circuit elements, as in the previously shown circuit, draw a diagram of a circuit that the students could use to determine whether resistor X is ohmic, including the appropriate placement of the meters. Clearly label your diagram.



ii. Describe the procedure you would use with your circuit to get enough data to determine whether resistor X is ohmic.

~~Change~~ (1) Connect circuit as shown after determining ε & r from part A
(2) Change R_1 while collecting (V) & (A) readings with each R_1 — (V) gives V_x, (A) gives I_x
(3) Plot V_x ~~A~~ vs. I_x should yield linear slope $= R_x$

iii. What would you graph using your data, and what would you look for on your graph to determine whether resistor X is ohmic?

see #3 above, constant slope within error shows Ohmic nature (constant R_x)

(c) Would your procedure or data analysis in part (b) need to be different if the internal resistance of the battery was nonohmic? Justify your answer.

~~No. There would be a different~~

Yes. According to KVL $\mathcal{E} - V_1 - V_2 = V_x$

$\frac{\mathcal{E} - Ir - IR_1}{I} = R_x$

$\frac{\mathcal{E}}{I_x} - r - R = R_x$ and if r changes R_x changes indep of I_x

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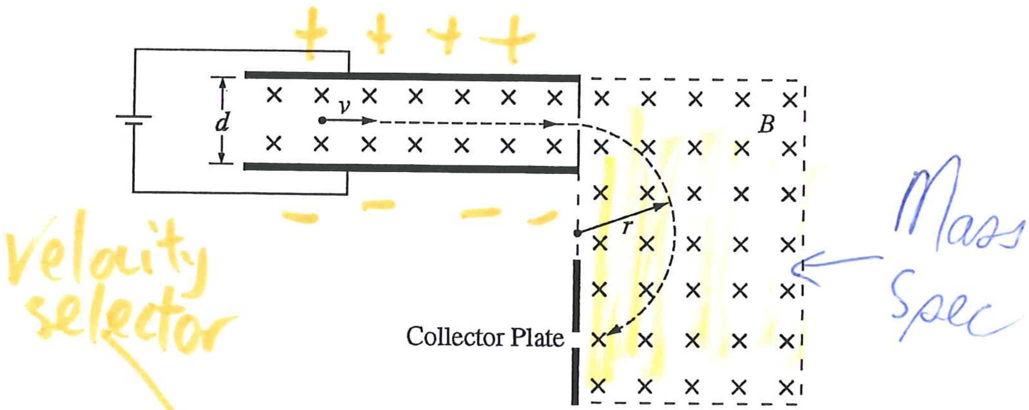

3. (12 points, suggested time 25 minutes)

A particle with unknown mass and charge is projected into the apparatus shown above. The particle moves with constant speed v as it passes undeflected through a pair of parallel plates, as shown above. The plates are separated by a distance d, and a constant potential difference V is maintained between them. A uniform magnetic field of magnitude B directed into the page exists both in the region between the plates and in the region to the right of the plates that is enclosed by the dashed lines. In the region to the right of the plates, the particle's path is circular with radius r. Assume the effects of gravity are negligible compared to other forces.

(a) Explain why the particle moves through the parallel plates undeflected in terms of the forces exerted on the particle.

The electrostatic force $F_e = \vec{E}q = \frac{\Delta V}{d}q$ must be equal & opposite to magnetic force $F_B = qvB$

(b) What is the sign of the charge on the particle? Justify your answer.

↑ from mass spec. at entry point

I from RHR ←
X B
↓ F_B

since current found using RHR is opposite to velocity, particle is negative

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$q = 1.6 \times 10^{-19}$

A magnetic field of 0.30 T is applied with the plate separation at 5.0×10^{-3} m. Singly ionized particles with various speeds enter the region between the plates, and only those with speed 2.0×10^{6} m/s are undeflected as they pass between the plates. These particles then reach the collector plate a distance of 0.42 m below the point at which they left the region between the parallel plates.

$\div 2 = r = .21 m$

(c) Based on your explanation in part (a), derive an algebraic expression for the potential difference that must be applied to produce the motion of the undeflected particles. Use that expression to calculate the numerical value of the potential difference.

$F_e = F_B$

$Eq = qvB$

$\frac{\Delta V}{d} = vB$ (1)

$\Delta V = vBd$

$= 3.0 \times 10^{3}$ V

(d) By analyzing the circular part of the motion, derive an algebraic expression for the mass of the particles. Use that expression to calculate a numerical value for the mass.

$F_c = F_B$

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

(2) $m = \frac{qBr}{v} = 5.04 \times 10^{-27}$ kg

(e) A scientist wants to use the apparatus to separate singly ionized atoms of ^{12}C and ^{14}C in order to use the ^{14}C in radiocarbon dating. Describe how the motion of the two isotopes of carbon in both regions of the apparatus leads to their separation, appropriately relating your description to the algebraic equations you wrote in parts (c) and (d).

1st region: motion unchanged due to independence of mass eqn. 1

2nd region: greater mass has greater inertia requiring larger radius ∴ C14 has bigger r than C12 eqn 2

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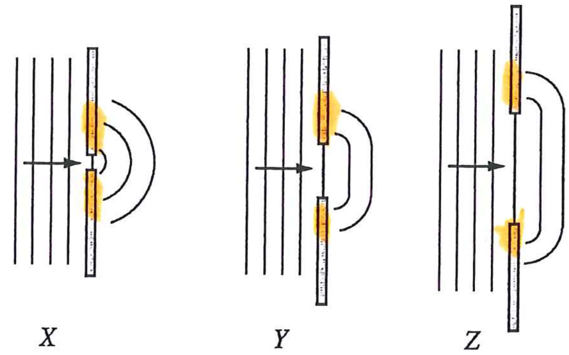
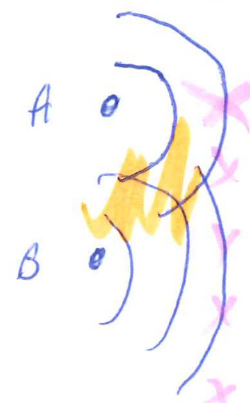


4. (10 points, suggested time 20 minutes)
The figures above labeled X, Y, and Z represent plane waves of the same wavelength incident on barriers that have openings of different sizes. Also shown are the shapes of the wave fronts beyond the barriers.

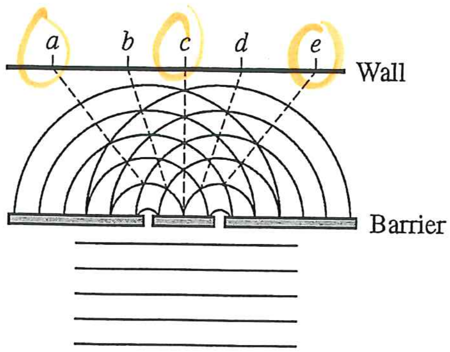
(a) One model of waves treats every point on a wave front as a point source. Give a clear, coherent, paragraph-length description of how this model can be used to explain the shape of the wave fronts beyond the barriers.

Huygen's Principle

with each point a source a wavelet propagates out w/ spherical front & wavelength λ & travels dist $d = vt$, ~~const~~ destructive interference between points elims shaded region leaving only X ~~wav~~ wavefront



Near boundaries in orange there are no outer sources for wavelets allowing for spherical propagation



The figure above represents another plane wave incident on a barrier with two identical openings, creating an interference pattern on the wall. Some positions in the pattern on the wall are labeled.

(b) In a few sentences, describe how the point-source model described in part (a) and the figure above can be used to explain the formation of the interference pattern on the wall.

As wavelets propagate out w/ spherical wave fronts each of the 2 sources may constructively interfere at a, c, e resulting in lrg amplitude while destructively interfere at B, D, resulting in zero amp.

(c) On the axes below, sketch the intensity of the waves that are incident on the wall. The labels correspond to the positions noted in the figure above.