AP® Physics B
2002 Free-Response Questions
Form B

TABLE OF INFORMATION FOR 2002

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J}/(\text{mol} \cdot \text{K})$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^8\ \text{m/s}$
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,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

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

PREFIXES

Factor	Prefix	Symbol
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	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2002

NEWTONIAN MECHANICS

$$\upsilon = \upsilon_0 + at$$

$$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$$

$$\upsilon^2 = \upsilon_0^2 + 2a(x - x_0)$$

$$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$$

$$F_{fric} \le \mu N$$

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

$$\tau = rF\sin\theta$$

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

$$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$$

$$K = \frac{1}{2}m\upsilon^2$$

$$\Delta U_g = mgh$$

$$W = \mathbf{F}\cdot\Delta\mathbf{r} = F\Delta r\cos\theta$$

$$P_{avg} = \frac{W}{\Delta t}$$

$$P = \mathbf{F}\cdot\mathbf{v} = F\upsilon\cos\theta$$

$$\mathbf{F}_s = -k\mathbf{x}$$

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

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

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

$$T = \frac{1}{f}$$

$$F_G = -\frac{Gm_1m_2}{r^2}$$

$$U_G = -\frac{Gm_1m_2}{r}$$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$$

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

$$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$$

$$E_{avg} = -\frac{V}{d}$$

$$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$$

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

$$C = \frac{\epsilon_0 A}{d}$$

$$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$$

$$I_{avg} = \frac{\Delta Q}{\Delta t}$$

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

$$V = IR$$

$$P = IV$$

$$C_p = \sum_i C_i$$

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

$$R_s = \sum_i R_i$$

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

$$F_B = q\upsilon B\sin\theta$$

$$F_B = BI\ell\sin\theta$$

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

$$\phi_m = \mathbf{B}\cdot\mathbf{A} = BA\cos\theta$$

$$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$$

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

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 = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2002

FLUID MECHANICS AND THERMAL PHYSICS

$$p = p_0 + \rho g h$$
$$F_{buoy} = \rho V g$$
$$A_1 \upsilon_1 = A_2 \upsilon_2$$
$$p + \rho g y + \frac{1}{2}\rho \upsilon^2 = \text{const.}$$
$$\Delta \ell = \alpha \ell_0 \Delta T$$
$$Q = mL$$
$$Q = mc\Delta T$$
$$p = \frac{F}{A}$$
$$pV = nRT$$
$$K_{avg} = \frac{3}{2} k_B T$$
$$\upsilon_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$$
$$W = -p\Delta V$$
$$Q = nc\Delta T$$
$$\Delta U = Q + W$$
$$\Delta U = nc_V \Delta T$$
$$e = \left|\frac{W}{Q_H}\right|$$
$$e_c = \frac{T_H - T_C}{T_H}$$

A = area
c = specific heat or molar specific heat
e = efficiency
F = force
h = depth
K_{avg} = average molecular kinetic energy
L = heat of transformation
ℓ = length
M = molecular mass
m = mass of sample
n = number of moles
p = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
υ = velocity or speed
υ_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$$E = hf = pc$$
$$K_{\max} = hf - \phi$$
$$\lambda = \frac{h}{p}$$
$$\Delta E = (\Delta m)c^2$$

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

WAVES AND OPTICS

$$\upsilon = f\lambda$$
$$n = \frac{c}{\upsilon}$$
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
$$\sin\theta_c = \frac{n_2}{n_1}$$
$$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$$
$$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$$
$$f = \frac{R}{2}$$
$$d \sin\theta = m\lambda$$
$$x_m \approx \frac{m\lambda L}{d}$$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
υ = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

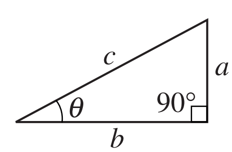
Circle
$A = \pi r^2$
$C = 2\pi r$

Parallelepiped
$V = \ell w h$

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

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

Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



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

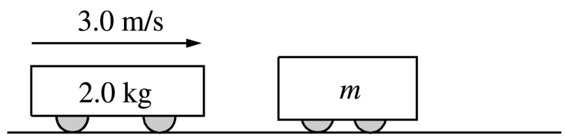
PHYSICS B

SECTION II

Time—90 minutes

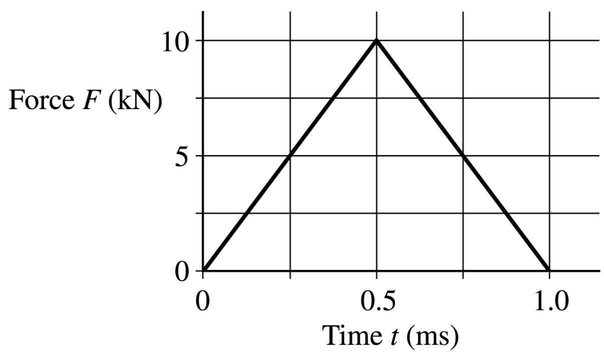
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1-4, and about 10 minutes for answering each of questions 5-7. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.



1. (15 points)

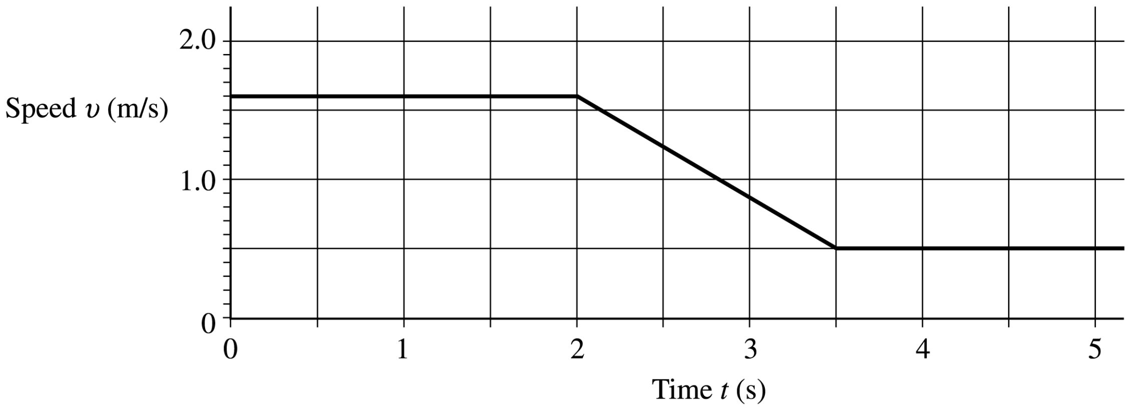
A 2.0 kg frictionless cart is moving at a constant speed of 3.0 m/s to the right on a horizontal surface, as shown above, when it collides with a second cart of undetermined mass m that is initially at rest. The force F of the collision as a function of time t is shown in the graph below, where $t = 0$ is the instant of initial contact. As a result of the collision, the second cart acquires a speed of 1.6 m/s to the right. Assume that friction is negligible before, during, and after the collision.



(a) Calculate the magnitude and direction of the velocity of the 2.0 kg cart after the collision.

(b) Calculate the mass m of the second cart.

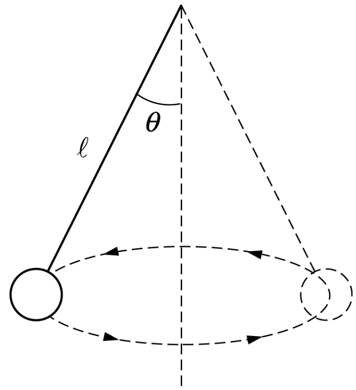
After the collision, the second cart eventually experiences a ramp, which it traverses with no frictional losses. The graph below shows the speed v of the second cart as a function of time t for the next 5.0 s, where $t = 0$ is now the instant at which the carts separate.



(c) Calculate the acceleration of the cart at $t = 3.0$ s.

(d) Calculate the distance traveled by the second cart during the 5.0 s interval after the collision ($0\text{ s} < t < 5.0\text{ s}$).

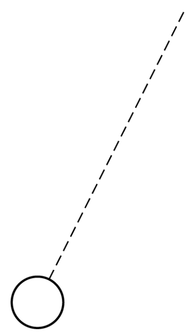
(e) State whether the ramp goes up or down and calculate the maximum elevation (above or below the initial height) reached by the second cart on the ramp during the 5.0 s interval after the collision ($0\text{ s} < t < 5.0\text{ s}$).



2. (15 points)

A ball attached to a string of length ℓ swings in a horizontal circle, as shown above, with a constant speed. The string makes an angle θ with the vertical, and T is the magnitude of the tension in the string. Express your answers to the following in terms of the given quantities and fundamental constants.

(a) On the figure below, draw and label vectors to represent all the forces acting on the ball when it is at the position shown in the diagram. The lengths of the vectors should be consistent with the relative magnitudes of the forces.

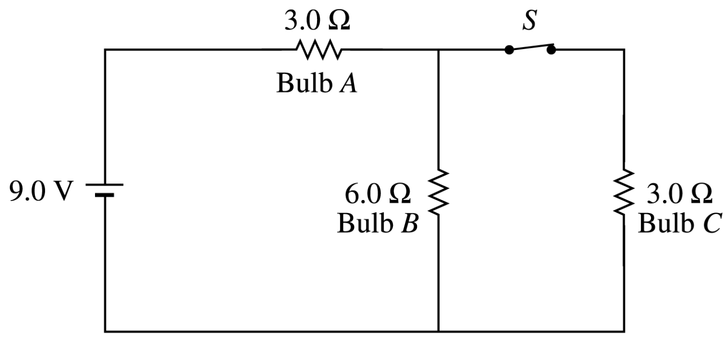


(b) Determine the mass of the ball.

(c) Determine the speed of the ball.

(d) Determine the frequency of revolution of the ball.

(e) Suppose that the string breaks as the ball swings in its circular path. Qualitatively describe the trajectory of the ball after the string breaks but before it hits the ground.



3. (15 points)

Lightbulbs of fixed resistance 3.0 Ω and 6.0 Ω, a 9.0 V battery, and a switch S are connected as shown in the schematic diagram above. The switch S is closed.

(a) Calculate the current in bulb A.

(b) Which lightbulb is brightest? Justify your answer.

(c) Switch S is then opened. By checking the appropriate spaces below, indicate whether the brightness of each lightbulb increases, decreases, or remains the same. Explain your reasoning for each lightbulb.

i. Bulb A: The brightness ___ increases ___ decreases ___ remains the same

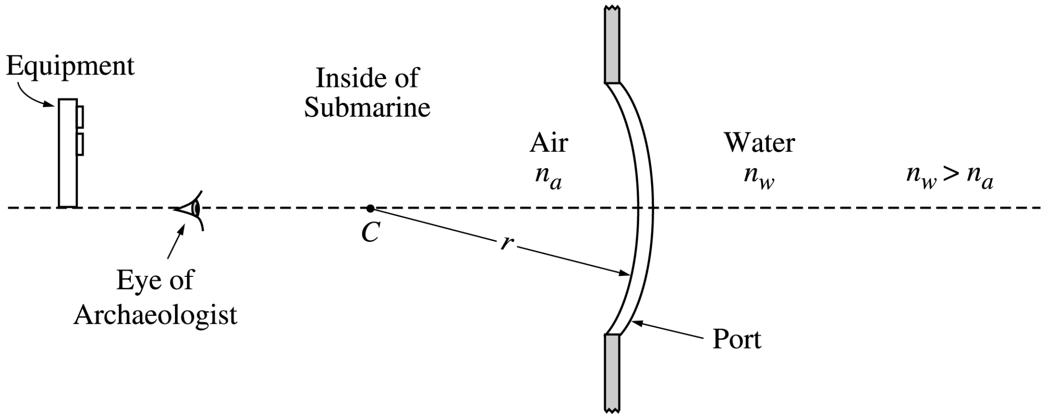
Explanation:

ii. Bulb B: The brightness ___ increases ___ decreases ___ remains the same

Explanation:

iii. Bulb C: The brightness ___ increases ___ decreases ___ remains the same

Explanation:

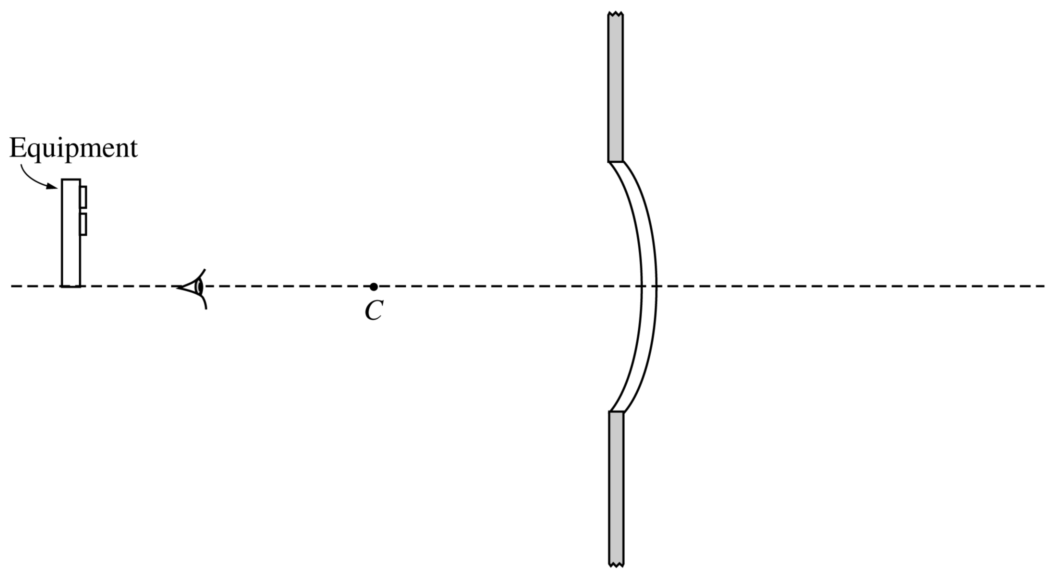


4. (15 points)

A marine archaeologist looks out the port of a research submarine, as shown above. The port is spherically shaped with center of curvature at point C and radius of curvature r. It is made of a material that has an index of refraction of n_w, the same as the index of refraction of seawater, which is greater than n_a, the index of refraction of air. The archaeologist is located to the left of point C and some equipment in the submarine is located behind the archaeologist. The archaeologist can see through the port, but the port also acts as a mirror so the archaeologist can see the reflection of the equipment.

(a) What is the focal length of the mirror?

(b) On the following figure, sketch a ray diagram to locate the position of the image of the equipment formed as a result of the mirror effect.



(c) Based on your ray diagram, check the appropriate spaces below to describe the image of the equipment formed as a result of the mirror effect.

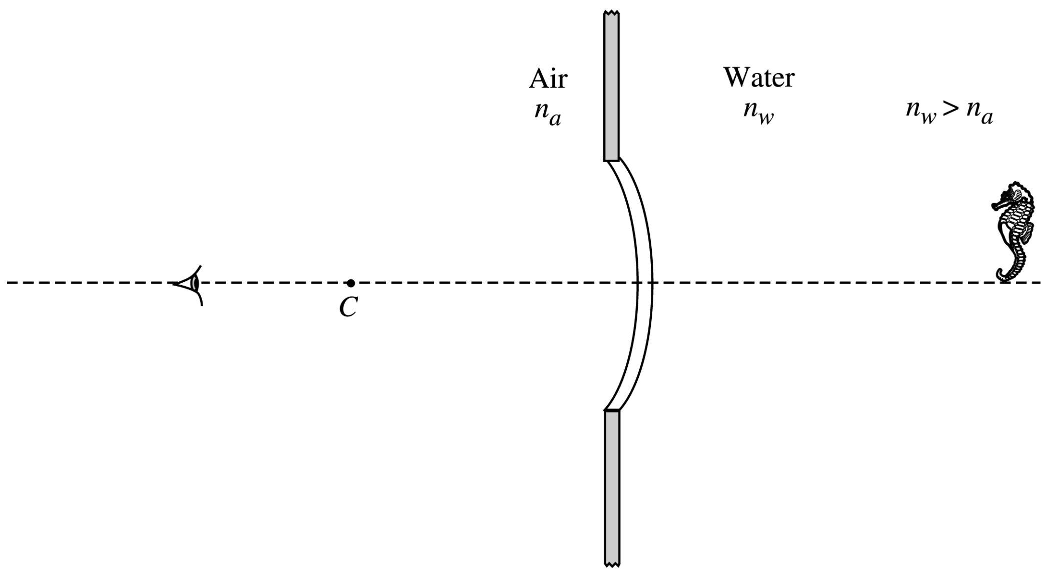
i. Image is: ___ upright ___ inverted

ii. Image is: ___ real ___ virtual

iii. Image is: ___ larger than the equipment ___ smaller than the equipment

The archaeologist also observes a seahorse located outside the port directly in front of the archeologist. Due to refraction of light at the inner surface of the port, the seahorse does not appear to the archaeologist to be at its actual location.

(d) On the following figure, sketch a ray diagram to locate the position of the image of the seahorse formed by the refraction of light at the port.



(e) Based on your ray diagram, check the appropriate spaces below to describe the image of the seahorse, as seen by the archaeologist, formed by the refraction of light at the port.

i. Image is: ___ upright ___ inverted

ii. Image is: ___ real ___ virtual

iii. Image is: ___ larger than the seahorse ___ smaller than the seahorse

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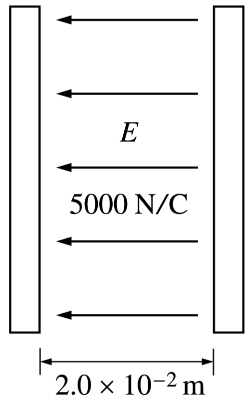

Note: Figure not drawn to scale.

5. (10 points)

Two parallel conducting plates, each of area $0.30\ \text{m}^2$, are separated by a distance of 2.0×10^{-2} m of air. One plate has charge $+Q$; the other has charge $-Q$. An electric field of 5000 N/C is directed to the left in the space between the plates, as shown in the diagram above.

(a) Indicate on the diagram which plate is positive (+) and which is negative (-).

(b) Determine the potential difference between the plates.

(c) Determine the capacitance of this arrangement of plates.

An electron is initially located at a point midway between the plates.

(d) Determine the magnitude of the electrostatic force on the electron at this location and state its direction.

(e) If the electron is released from rest at this location midway between the plates, determine its speed just before striking one of the plates. Assume that gravitational effects are negligible.

6. (10 points)

A sealed steel canister is being used to store neon gas (atomic mass = 20.2 u). The mass of the steel canister alone is 12.0 kg, and it has an interior volume of 8.00 liters = $8.00 \times 10^{-3}\ \text{m}^3$. There are 4.50 moles of neon gas in the canister, and the temperature of the entire system is 300 K.

Reference information:

Specific heat of steel = $448\ \text{J kg}^{-1}\,\text{K}^{-1}$

Specific heat of neon = $12.5\ \text{J mole}^{-1}\,\text{K}^{-1}$

Specific heat of water = $4186\ \text{J kg}^{-1}\,\text{K}^{-1}$

Heat of fusion of water = $3.33 \times 10^5\ \text{J kg}^{-1}$

Density of water = $1.00 \times 10^3\ \text{kg m}^{-3}$

Density of ice = $0.917 \times 10^3\ \text{kg m}^{-3}$

(a) Determine the pressure within the cylinder.

The sealed cylinder is now placed in a large tank containing a mixture of ice and water at 273 K. You may neglect any change in the volume of the cylinder.

(b) Determine the pressure of the neon gas after the cylinder and its contents have reached thermal equilibrium with the ice-water mixture.

(c) Determine the mass of the ice that melts during the equilibration of the cylinder.

7. (10 points)

An experimenter determines that when a beam of monoenergetic electrons bombards a sample of a pure gas, atoms of the gas are excited if the kinetic energy of each electron in the beam is 3.70 eV or greater.

(a) Determine the deBroglie wavelength of 3.70 eV electrons.

(b) Once the gas is excited by 3.70 eV electrons, it emits monochromatic light. Determine the wavelength of this light.

Experiments reveal that two additional wavelengths are emitted if the beam energy is raised to at least 4.90 eV.

(c) In the space below construct an energy-level diagram consistent with this information and determine the energies of the photons associated with those two additional wavelengths.

END OF EXAMINATION