CollegeBoard
Advanced Placement Program

AP® Physics B
2004 Free-Response Questions
Form B

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ u = 1.66 \times 10^{-27}$ kg
	$= 931$ MeV/c^2
Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}$ C
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}
Universal gas constant,	$R = 8.31$ J/(mol · K)
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K
Speed of light,	$c = 3.00 \times 10^8$ m/s
Planck's constant,	$h = 6.63 \times 10^{-34}$ J · s
	$= 4.14 \times 10^{-15}$ eV · s
	$hc = 1.99 \times 10^{-25}$ J · m
	$= 1.24 \times 10^3$ eV · nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N · m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9$ N · m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T · m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}$ (T · m)/A
Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg · s^2
Acceleration due to gravity at the Earth's surface,	$g = 9.8$ m/s^2
1 atmosphere pressure,	1 atm $= 1.0 \times 10^5$ N/m^2
	$= 1.0 \times 10^5$ Pa
1 electron volt,	1 eV $= 1.60 \times 10^{-19}$ 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 2004 and 2005

NEWTONIAN MECHANICS

$v = v_0 + at$

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

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

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

$F_{fric} \le \mu N$

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

$\tau = rF \sin\theta$

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

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

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

$\Delta U_g = mgh$

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

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

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

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

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

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

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

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

$F_G = -\frac{Gm_1 m_2}{r^2}$

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

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
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$

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

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r}$

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

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

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

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

$R_s = \sum_i R_i$

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

$F_B = qvB\sin\theta$

$F_B = BI\ell\sin\theta$

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

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

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

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

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
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho g h$

$F_{buoy} = \rho V g$

$A_1 \upsilon_1 = A_2 \upsilon_2$

$P + \rho g y + \frac{1}{2}\rho \upsilon^2 = \text{const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

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

$PV = nRT$

$K_{avg} = \frac{3}{2} k_B T$

$\upsilon_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
K_{avg} = average molecular kinetic energy
ℓ = length
M = molar mass
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

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

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

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

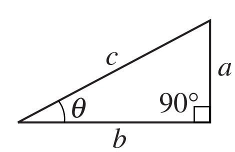
Right Triangle
$a^2 + b^2 = c^2$

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

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

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

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



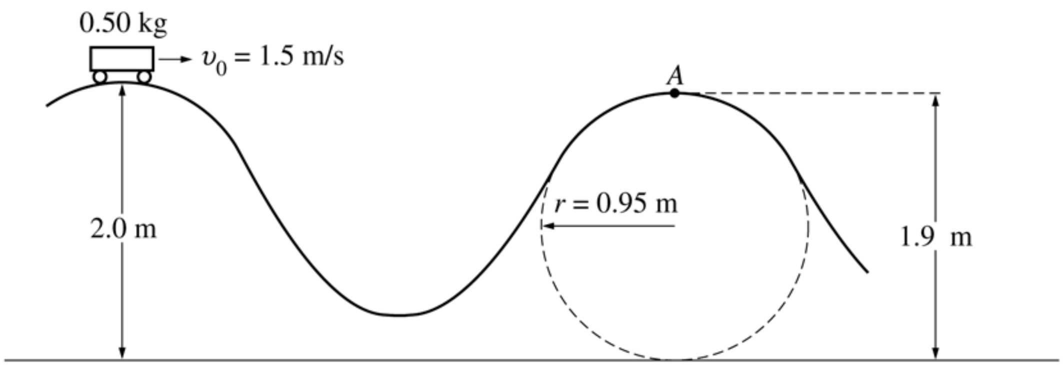
PHYSICS B

SECTION II

Time—90 minutes

6 Questions

Directions: Answer all six questions, which are weighted according to the points indicated. The suggested time is about 17 minutes for answering each of questions 1-4, and about 11 minutes for answering each of questions 5-6. 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 designer is working on a new roller coaster, and she begins by making a scale model. On this model, a car of total mass 0.50 kg moves with negligible friction along the track shown in the figure above. The car is given an initial speed $v_0 = 1.5$ m/s at the top of the first hill of height 2.0 m. Point A is located at a height of 1.9 m at the top of the second hill, the upper part of which is a circular arc of radius 0.95 m.

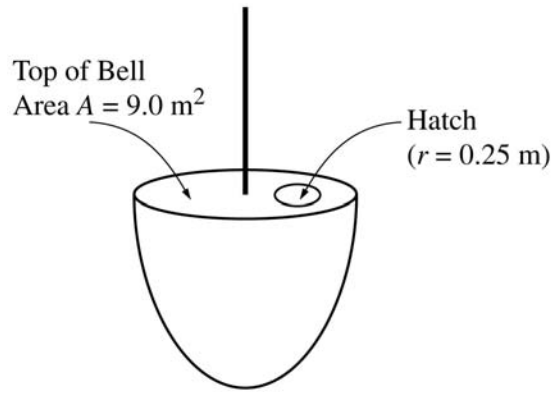
(a) Calculate the speed of the car at point A.

(b) On the figure of the car below, draw and label vectors to represent the forces on the car at point A.

(c) Calculate the magnitude of the force of the track on the car at point A.

(d) In order to stop the car at point A, some friction must be introduced. Calculate the work that must be done by the friction force in order to stop the car at point A.

(e) Explain how to modify the track design to cause the car to lose contact with the track at point A before descending down the track. Justify your answer.



2. (15 points)

The experimental diving bell shown above is lowered from rest at the ocean's surface and reaches a maximum depth of 80 m. Initially it accelerates downward at a rate of $0.10\ m/s^2$ until it reaches a speed of $2.0\ m/s$, which then remains constant. During the descent, the pressure inside the bell remains constant at 1 atmosphere. The top of the bell has a cross-sectional area $A = 9.0\ m^2$. The density of seawater is $1025\ kg/m^3$.

(a) Calculate the total time it takes the bell to reach the maximum depth of 80 m.

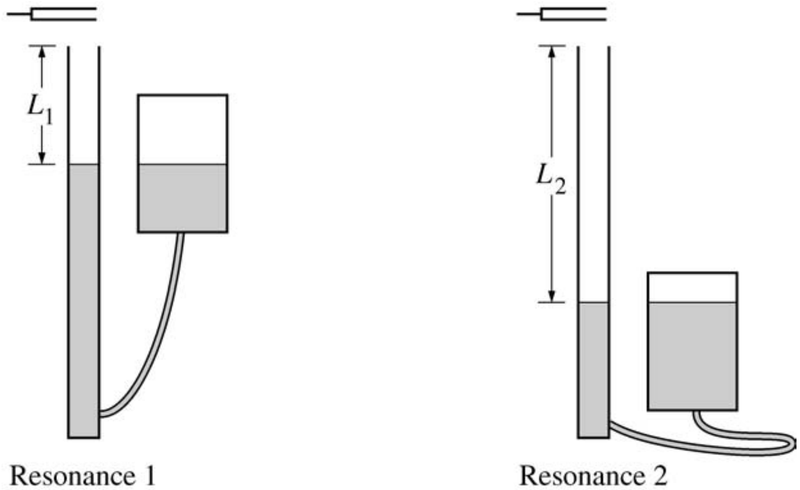
(b) Calculate the weight of the water on the top of the bell when it is at the maximum depth.

(c) Calculate the absolute pressure on the top of the bell at the maximum depth.

On the top of the bell there is a circular hatch of radius $r = 0.25$ m.

(d) Calculate the minimum force necessary to lift open the hatch of the bell at the maximum depth.

(e) What could you do to reduce the force necessary to open the hatch at this depth? Justify your answer.



Note: Figure not drawn to scale.

3. (15 points)

A vibrating tuning fork is held above a column of air, as shown in the diagrams above. The reservoir is raised and lowered to change the water level, and thus the length of the column of air. The shortest length of air column that produces a resonance is $L_1 = 0.25$ m , and the next resonance is heard when the air column is $L_2 = 0.80$ m long. The speed of sound in air at 20°C is 343 m/s and the speed of sound in water is 1490 m/s.

(a) Calculate the wavelength of the standing sound wave produced by this tuning fork.

(b) Calculate the frequency of the tuning fork that produces the standing wave, assuming the air is at 20°C.

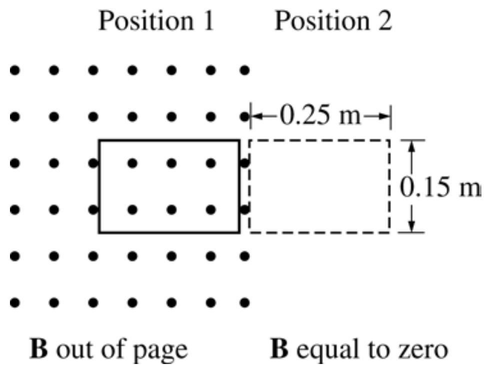
(c) Calculate the wavelength of the sound waves produced by this tuning fork in the water.

(d) The water level is lowered again until a third resonance is heard. Calculate the length L_3 of the air column that produces this third resonance.

(e) The student performing this experiment determines that the temperature of the room is actually slightly higher than 20°C. Is the calculation of the frequency in part (b) too high, too low, or still correct?

_____ Too high _____ Too low _____ Still correct

Justify your answer.



4. (15 points)

A 20-turn wire coil in the shape of a rectangle, 0.25 m by 0.15 m, has a resistance of $5.0\ \Omega$. In position 1 shown above, the loop is in a uniform magnetic field **B** of 0.20 T. The field is directed out of the page, perpendicular to the plane of the loop. The loop is pulled to the right at a constant velocity, reaching position 2 in 0.50 s, where **B** is equal to zero.

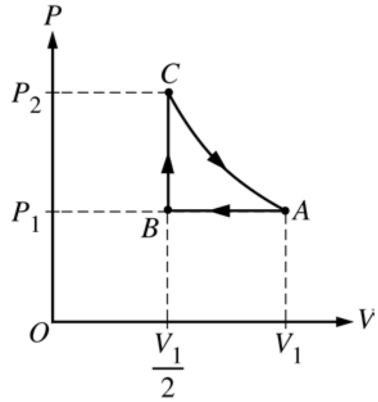
(a) Calculate the average emf induced in the 20-turn coil during this period.

(b) Calculate the magnitude of the current induced in the 20-turn coil and state its direction.

(c) Calculate the power dissipated in the 20-turn coil.

(d) Calculate the magnitude of the average force necessary to remove the 20-turn coil from the magnetic field.

(e) Identical wire is used to add 20 more turns of wire to the original coil. How does this affect the current in the coil? Justify your answer.



5. (10 points)

One mole of an ideal gas is initially at pressure P_1, volume V_1, and temperature T_1, represented by point A on the PV diagram above. The gas is taken around cycle $ABCA$ shown. Process AB is isobaric, process BC is isochoric, and process CA is isothermal.

(a) Calculate the temperature T_2 at the end of process AB in terms of temperature T_1.

(b) Calculate the pressure P_2 at the end of process BC in terms of pressure P_1.

(c) Calculate the net work done on the gas when it is taken from A to B to C. Express your answer in terms of P_1 and V_1.

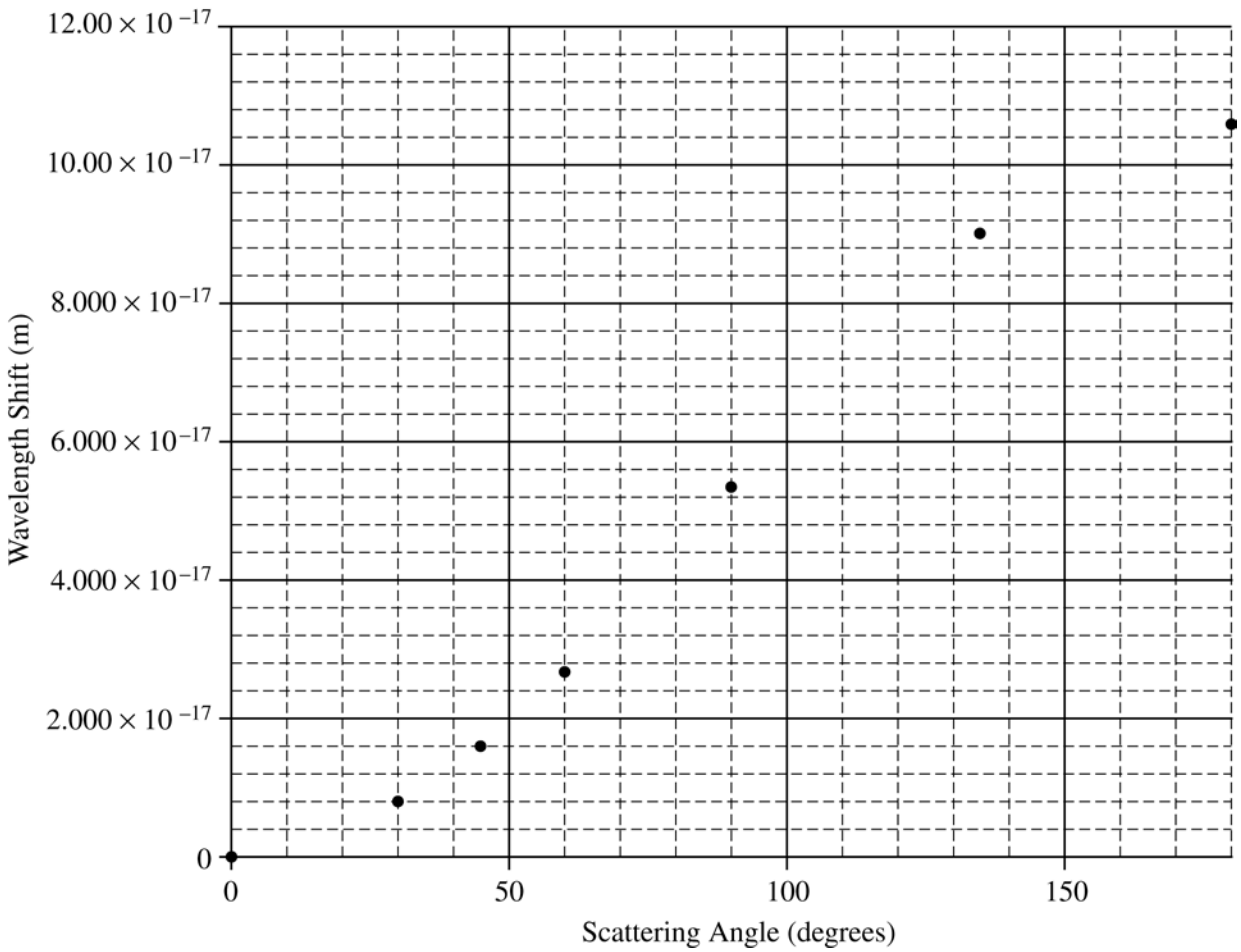
(d) Indicate below all of the processes that result in heat being added to the gas.

____ AB ____ BC ____ CA

Justify your answer.

6. (10 points)

An incident gamma ray photon of wavelength 1.400×10^{-14} m is scattered off a stationary nucleus. The shift in wavelength of the photon is measured for various scattering angles, and the results are plotted on the graph shown below.



(a) On the graph, sketch a best-fit curve to the data.

In one of the trials, the photon is scattered at an angle of 120° with its original direction.

(b) Calculate the wavelength of this photon after it is scattered off the nucleus.

(c) Calculate the momentum of this scattered photon.

(d) Calculate the energy that this scattering event imparts to the recoiling nucleus.

END OF EXAMINATION