Student Name ________

Teacher Name Mr. Helmer

School Manalapan High School

2000

3WBP

The College Board
Advanced Placement Examination
PHYSICS C
SECTION II

TABLE OF INFORMATION FOR 2000

**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, | $N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$ |
| 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, | $\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2$ |
| 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, | $\mu_0 = 4\pi \times 10^{-7}$ (T · m)/A |
| Magnetic constant, | $k' = \mu_0/4\pi = 10^{-7}$ (T · m)/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, | $1 \text{ atm} = 1.0 \times 10^5\ \text{N/m}^2$ |
| | $= 1.0 \times 10^5$ Pa |
| 1 electron volt, | $1 \text{ eV} = 1.60 \times 10^{-19}$ 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.

This insert may be used for reference and/or scratchwork as you answer the free-response questions, but be sure to show all your work and your answers in the pink booklet. No credit will be given for work shown on this green insert.

# ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2000

## MECHANICS

$v = v_0 + at$

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

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

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

$\mathbf{F} = \frac{d\mathbf{p}}{dt}$

$\mathbf{J} = \int \mathbf{F}\, dt = \Delta\mathbf{p}$

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

$F_{fric} \leq \mu N$

$W = \int \mathbf{F} \cdot d\mathbf{s}$

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

$P = \frac{dW}{dt}$

$\Delta U_g = mgh$

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

$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$

$\sum \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$

$I = \int r^2 dm = \sum mr^2$

$\mathbf{r}_{cm} = \sum m\mathbf{r} / \sum m$

$v = r\omega$

$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

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

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

$\mathbf{F}_G = -\frac{Gm_1m_2}{r^2}\,\hat{\mathbf{r}}$

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

$a$ = acceleration
$F$ = force
$f$ = frequency
$h$ = height
$I$ = rotational inertia
$J$ = impulse
$K$ = kinetic energy
$k$ = spring constant
$\ell$ = length
$L$ = angular momentum
$m$ = mass
$N$ = normal force
$P$ = power
$p$ = momentum
$r$ = radius or distance
$s$ = displacement
$T$ = period
$t$ = time
$U$ = potential energy
$v$ = velocity or speed
$W$ = work
$x$ = position
$\mu$ = coefficient of friction
$\theta$ = angle
$\tau$ = torque
$\omega$ = angular speed
$\alpha$ = angular acceleration

## ELECTRICITY AND MAGNETISM

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

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

$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$

$E = -\frac{dV}{dr}$

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

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

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

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

$C_p = \sum_i C_i$

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

$I = \frac{dQ}{dt}$

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

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

$V = IR$

$R_s = \sum_i R_i$

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

$P = IV$

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

$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$

$\mathbf{F} = \int I\, d\boldsymbol{\ell} \times \mathbf{B}$

$B_s = \mu_0 nI$

$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$

$\mathcal{E} = -\frac{d\phi_m}{dt}$

$\mathcal{E} = -L\frac{dI}{dt}$

$U_L = \frac{1}{2}LI^2$

$A$ = area
$B$ = magnetic field
$C$ = capacitance
$d$ = distance
$E$ = electric field
$\mathcal{E}$ = emf
$F$ = force
$I$ = current
$L$ = inductance
$\ell$ = length
$n$ = number of loops of wire per unit length
$P$ = power
$Q$ = charge
$q$ = point charge
$R$ = resistance
$r$ = distance
$t$ = time
$U$ = potential or stored energy
$V$ = electric potential
$v$ = velocity or speed
$\rho$ = resistivity
$\phi_m$ = magnetic flux
$\kappa$ = dielectric constant

## ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2000

### GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

Parallelepiped

$V = \ell wh$

Cylinder

$V = \pi r^2 \ell$

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

Sphere

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

$S = 4\pi r^2$

Right Triangle

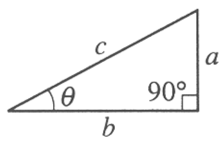
$a^2 + b^2 = c^2$

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

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

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

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




### CALCULUS

$$\frac{df}{dx} = \frac{df}{du}\cdot\frac{du}{dx}$$

$$\frac{d}{dx}\left(x^n\right) = nx^{n-1}$$

$$\frac{d}{dx}\left(e^x\right) = e^x$$

$$\frac{d}{dx}(\ln x) = \frac{1}{x}$$

$$\frac{d}{dx}(\sin x) = \cos x$$

$$\frac{d}{dx}(\cos x) = -\sin x$$

$$\int x^n\,dx = \frac{1}{n+1}x^{n+1},\ n \neq -1$$

$$\int e^x\,dx = e^x$$

$$\int \frac{dx}{x} = \ln|x|$$

$$\int \cos x\,dx = \sin x$$

$$\int \sin x\,dx = -\cos x$$

**PHYSICS C**

**Section II, MECHANICS**

**Time—45 minutes**

**3 Questions**

**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.

Mech 1.

You are conducting an experiment to measure the acceleration due to gravity $g_u$ at an unknown location. In the measurement apparatus, a simple pendulum swings past a photogate located at the pendulum's lowest point, which records the time $t_{10}$ for the pendulum to undergo 10 full oscillations. The pendulum consists of a sphere of mass $m$ at the end of a string and has a length $\ell$. There are four versions of this apparatus, each with a different length. All four are at the unknown location, and the data shown below are sent to you during the experiment.

| $\ell$ (cm) | $t_{10}$ (s) | $T$ (s) | $T^2$ ($s^2$) |
|---|---|---|---|
| 12 | 7.62 | | |
| 18 | 8.89 | | |
| 21 | 10.09 | | |
| 32 | 12.08 | | |

(a) For each pendulum, calculate the period $T$ and the square of the period. Use a reasonable number of significant figures. Enter these results in the table above.

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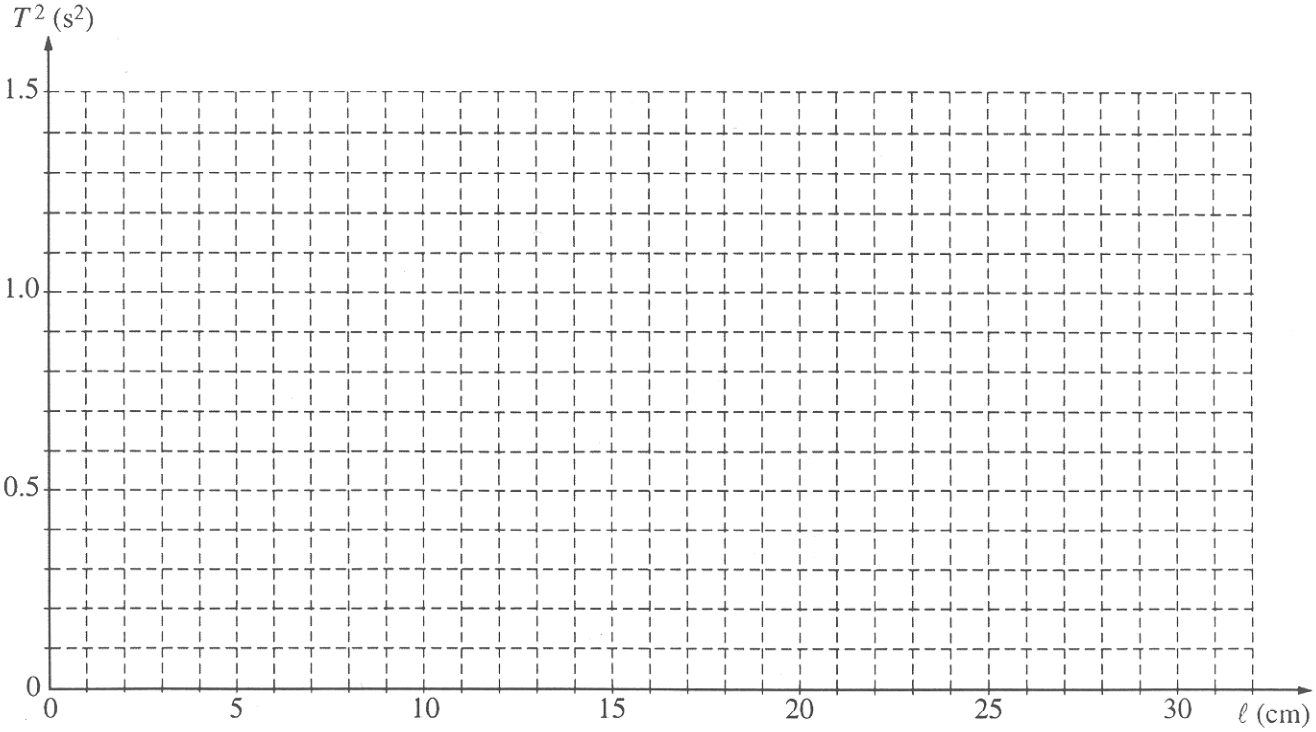
(b) On the axes below, plot the square of the period versus the length of the pendulum. Draw a best-fit straight line for this data.




(c) Assuming that each pendulum undergoes small amplitude oscillations, from your fit determine the experimental value $g_{exp}$ of the acceleration due to gravity at this unknown location. Justify your answer.

(d) If the measurement apparatus allows a determination of $g_u$ that is accurate to within 4%, is your experimental value in agreement with the value 9.80 m/s$^2$ ? Justify your answer.

(e) Someone informs you that the experimental apparatus is in fact near Earth's surface, but that the experiment has been conducted inside an elevator with a constant acceleration $a$. Assuming that your experimental value $g_{exp}$ is exact, determine the magnitude and direction of the elevator's acceleration.

Mech 2.

A rubber ball of mass $m$ is dropped from a cliff. As the ball falls, it is subject to air drag (a resistive force caused by the air). The drag force on the ball has magnitude $bv^2$, where $b$ is a constant drag coefficient and $v$ is the instantaneous speed of the ball. The drag coefficient $b$ is directly proportional to the cross-sectional area of the ball and the density of the air and does not depend on the mass of the ball. As the ball falls, its speed approaches a constant value called the terminal speed.

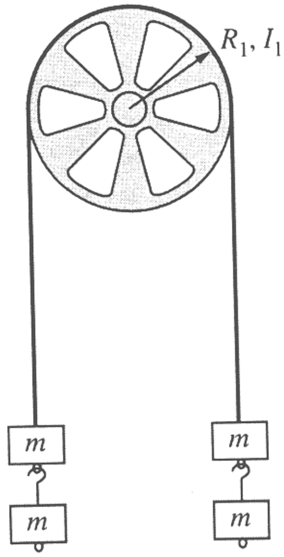
(a) On the figure below, draw and label all the forces on the ball at some instant before it reaches terminal speed.

(b) State whether the magnitude of the acceleration of the ball of mass $m$ increases, decreases, or remains the same as the ball approaches terminal speed. Explain.

(c) Write, but do NOT solve, a differential equation for the instantaneous speed $v$ of the ball in terms of time $t$, the given quantities, and fundamental constants.

(d) Determine the terminal speed $v_t$ in terms of the given quantities and fundamental constants.

(e) Determine the energy dissipated by the drag force during the fall if the ball is released at height $h$ and reaches its terminal speed before hitting the ground, in terms of the given quantities and fundamental constants.




Mech 3.

A pulley of radius $R_1$ and rotational inertia $I_1$ is mounted on an axle with negligible friction. A light cord passing over the pulley has two blocks of mass $m$ attached to either end, as shown above. Assume that the cord does <u>not</u> slip on the pulley. Determine the answers to parts (a) and (b) in terms of $m$, $R_1$, $I_1$, and fundamental constants.

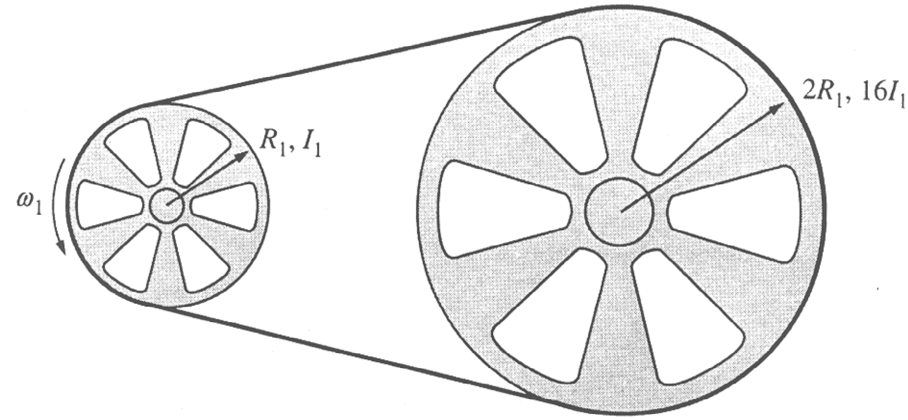
(a) Determine the tension $T$ in the cord.

(b) One block is now removed from the right and hung on the left. When the system is released from rest, the three blocks on the left accelerate downward with an acceleration $\frac{g}{3}$. Determine the following.

i. The tension $T_3$ in the section of cord supporting the three blocks on the left

ii. The tension $T_1$ in the section of cord supporting the single block on the right

iii. The rotational inertia $I_1$ of the pulley




(c) The blocks are now removed and the cord is tied into a loop, which is passed around the original pulley and a second pulley of radius $2R_1$ and rotational inertia $16I_1$. The axis of the original pulley is attached to a motor that rotates it at angular speed $\omega_1$, which in turn causes the larger pulley to rotate. The loop does not slip on the pulleys. Determine the following in terms of $I_1$, $R_1$, and $\omega_1$.

i. The angular speed $\omega_2$ of the larger pulley

ii. The angular momentum $L_2$ of the larger pulley

iii. The total kinetic energy of the system

## STOP

**END OF SECTION II, MECHANICS**

**IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK ON SECTION II, MECHANICS, ONLY. DO NOT TURN TO ANY OTHER TEST MATERIALS.**

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NO TEST MATERIAL ON THIS PAGE

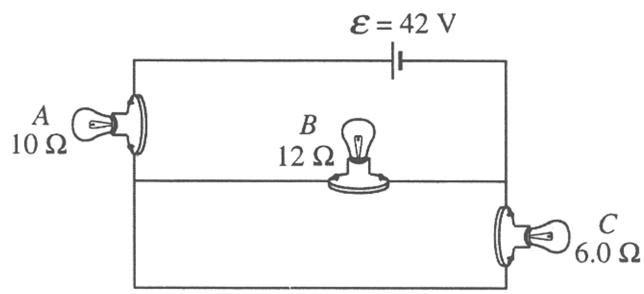
# PHYSICS C

## Section II, ELECTRICITY AND MAGNETISM

**Time—45 minutes**

**3 Questions**

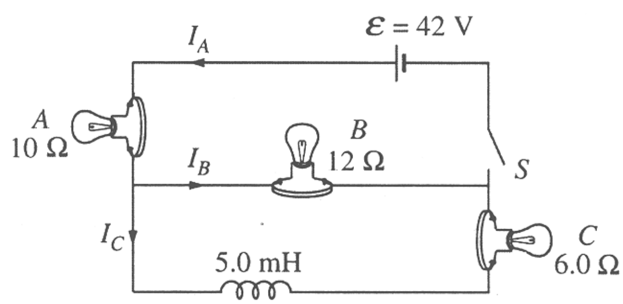
**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.




E & M 1.

Lightbulbs $A$, $B$, and $C$ are connected in the circuit shown above.

(a) List the bulbs in order of their brightness, from brightest to least bright. If any bulbs have the same brightness, state which ones. Justify your answer.




Now a switch $S$ and a 5.0 mH inductor are added to the circuit, as shown above. The switch is closed at time $t = 0$.

(b) Determine the currents $I_A$, $I_B$, and $I_C$ for the following times.

i. Immediately after the switch is closed

ii. A long time after the switch is closed

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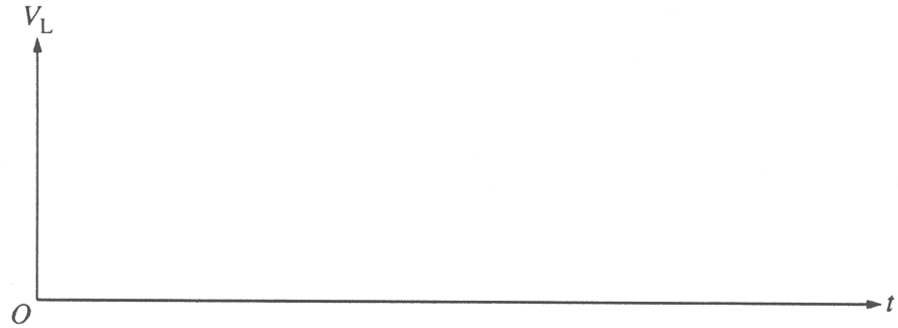
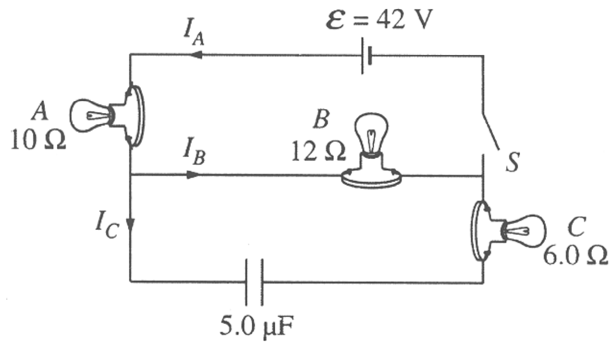
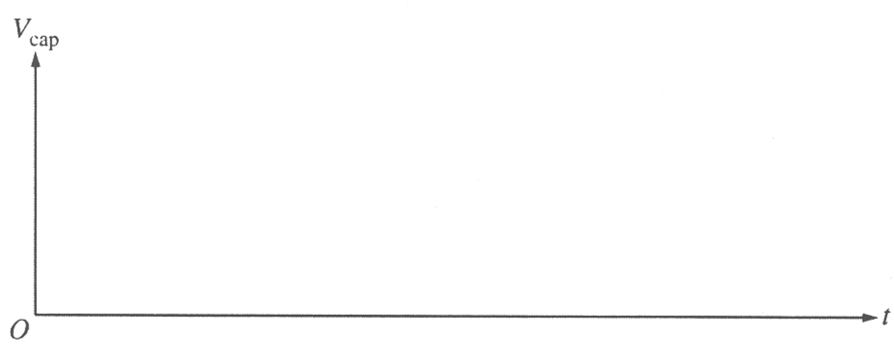
(c) On the axes below, sketch the magnitude of the potential difference $V_L$ across the inductor as a function of time, from immediately after the switch is closed until a long time after the switch is closed.




(d) Now consider a similar circuit with an uncharged 5.0 μF capacitor instead of the inductor, as shown above. The switch is again closed at time $t = 0$. On the axes below, sketch the magnitude of the potential difference $V_{cap}$ across the capacitor as a function of time, from immediately after the switch is closed until a long time after the switch is closed.

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E & M 2.

Three particles, $A$, $B$, and $C$, have equal positive charges $Q$ and are held in place at the vertices of an equilateral triangle with sides of length $\ell$, as shown in the figures below. The dotted lines represent the bisectors for each side. The base of the triangle lies on the $x$-axis, and the altitude of the triangle lies on the $y$-axis.

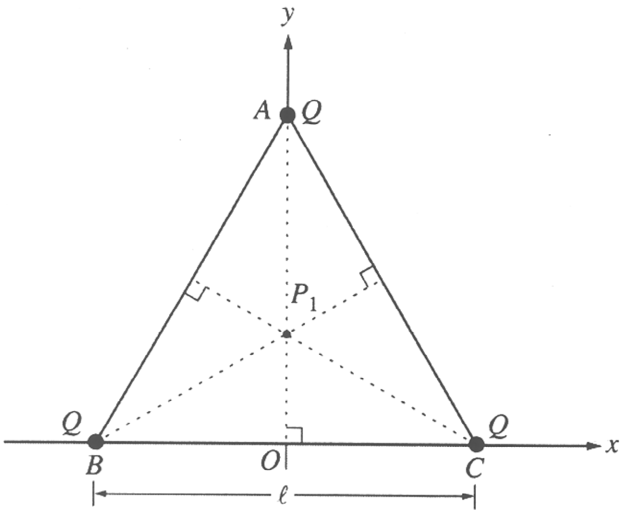



Figure 1

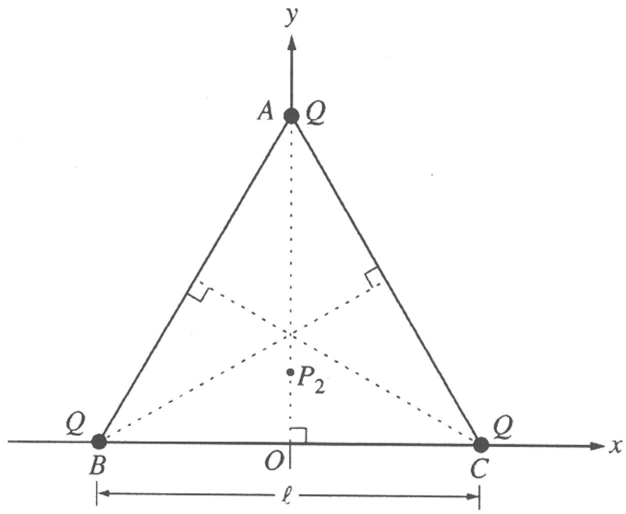



Figure 2

(a)

i. Point $P_1$, the intersection of the three bisectors, locates the geometric center of the triangle and is one point where the electric field is zero. On Figure 1 above, draw the electric field vectors $\mathbf{E}_A$, $\mathbf{E}_B$, and $\mathbf{E}_C$ at $P_1$ due to each of the three charges. Be sure your arrows are drawn to reflect the relative magnitude of the fields.

ii. Another point where the electric field is zero is point $P_2$ at $(0, y_2)$. On Figure 2 above, draw electric field vectors $\mathbf{E}_A$, $\mathbf{E}_B$, and $\mathbf{E}_C$ at $P_2$ due to each of the three point charges. Indicate below whether the magnitude of each of these vectors is greater than, less than, or the same as for point $P_1$.

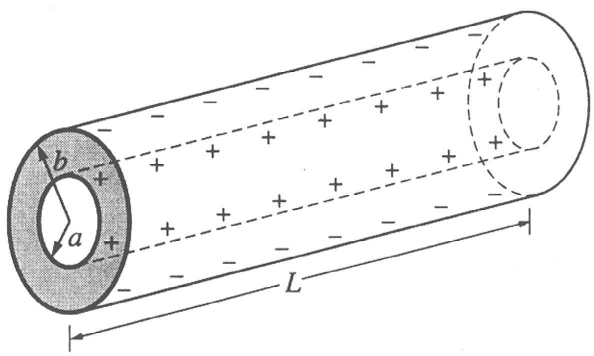
| | Greater than at $P_1$ | Less than at $P_1$ | The same as at $P_1$ |
|---|---|---|---|
| $E_A$ | | | |
| $E_B$ | | | |
| $E_C$ | | | |

GO ON TO THE NEXT PAGE.

(b) Explain why the $x$-component of the total electric field is zero at any point on the $y$-axis.

(c) Write a general expression for the electric potential $V$ at any point on the $y$-axis inside the triangle in terms of $Q$, $\ell$, and $y$.

(d) Describe how the answer to part (c) could be used to determine the $y$-coordinates of points $P_1$ and $P_2$ at which the electric field is zero. (You do not need to actually determine these coordinates.)




E & M 3.

A capacitor consists of two conducting, coaxial, cylindrical shells of radius $a$ and $b$, respectively, and length $L >> b$. The space between the cylinders is filled with oil that has a dielectric constant $\kappa$. Initially both cylinders are uncharged, but then a battery is used to charge the capacitor, leaving a charge $+Q$ on the inner cylinder and $-Q$ on the outer cylinder, as shown above. Let $r$ be the radial distance from the axis of the capacitor.

(a) Using Gauss's law, determine the electric field midway along the length of the cylinder for the following values of $r$, in terms of the given quantities and fundamental constants. Assume end effects are negligible.

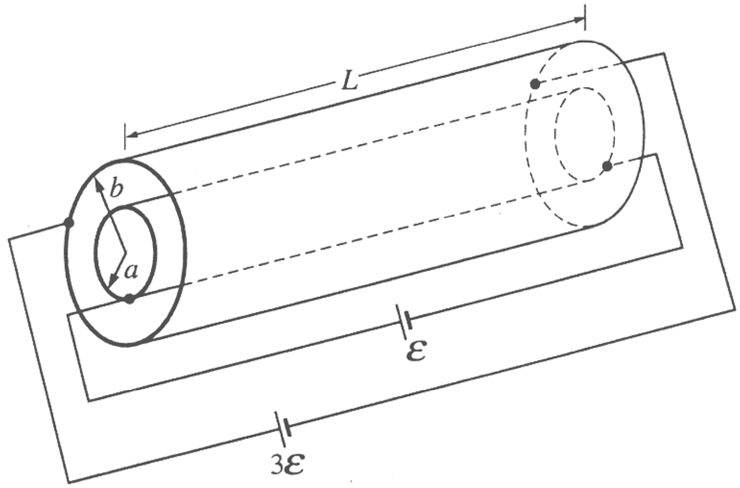
i. $a < r < b$

ii. $b < r << L$

(b) Determine the following in terms of the given quantities and fundamental constants.

i. The potential difference across the capacitor

ii. The capacitance of this capacitor




(c) Now the capacitor is discharged and the oil is drained from it. As shown above, a battery of emf $\mathcal{E}$ is connected to opposite ends of the inner cylinder and a battery of emf $3\mathcal{E}$ is connected to opposite ends of the outer cylinder. Each cylinder has resistance $R$. Assume that end effects and the contributions to the magnetic field from the wires are negligible. Using Ampere's law, determine the magnitude $B$ of the magnetic field midway along the length of the cylinders due to the current in the cylinders for the following values of $r$.

i. $a < r < b$

ii. $b < r << L$

# STOP

**END OF SECTION II, ELECTRICITY AND MAGNETISM**

**IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK ON SECTION II, ELECTRICITY AND MAGNETISM, ONLY. DO NOT TURN TO ANY OTHER TEST MATERIALS.**

NO TEST MATERIAL ON THIS PAGE

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