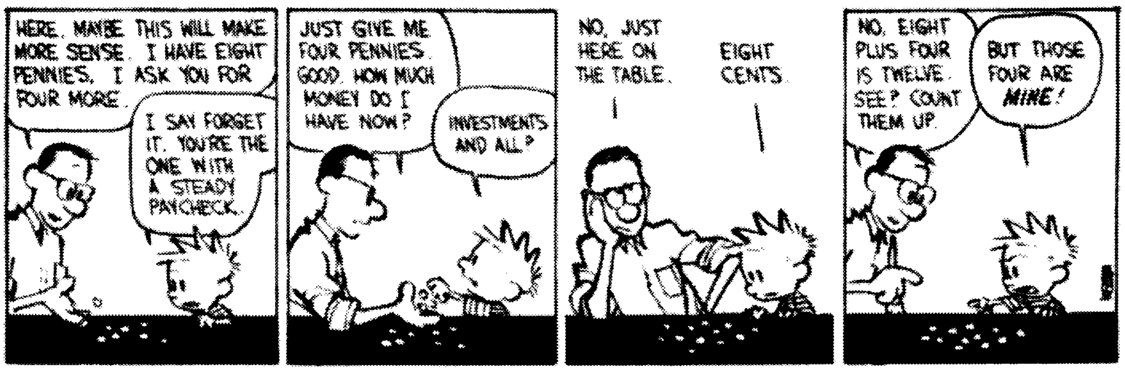
PHYS 2020: College Physics II

Midterm Number 1, Spring Semester 2008

NAME	SOLUTIONS
FAVORITE ELECTRICAL PUN	THAT WAS AN ELECTRIFYING LECTURE! THAT RESULT IS SHOCKING! DON'T BE SO NEGATIVE!



DO NOT OPEN THIS EXAM UNTIL YOU ARE TOLD TO START!

Welcome to Midterm 1! Take a deep breath, relax. You know how to do physics – this is simply covering material you already know how to do.

INSTRUCTIONS:

- ▷ You must show your work for full credit!
- ▷ Circle your final answers; make sure all your answers have been labeled **with units**!
- ▷ If you have questions, ask!

You may find some of the following formulae useful:

Charge, Forces & Fields

$$F_{coul} = k\frac{|q_1|\,|q_2|}{r^2} \qquad E = \frac{F_{coul}}{|q_2|} = k\frac{|q_1|}{r^2} \qquad E_{tot} = E_1 + E_2 + \ldots$$

$$\Phi = E \cdot A \cdot \cos\theta \quad (Electric\ Flux) \qquad \Phi = \frac{q_{enc}}{\epsilon_o} \quad (Gauss'\ Law)$$

Electric Potential

$$U_E = k\frac{|q_1|\,|q_2|}{r} \qquad V = \frac{U_E}{|q_2|} = k\frac{|q_1|}{r} \qquad V = E \cdot d$$

$$C = \frac{Q}{V} \qquad C = \epsilon_o\frac{A}{d} \qquad C = \kappa C_o \qquad E = \frac{E_o}{\kappa}$$

$$U_E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$$

Circuits

$$I = \frac{\Delta Q}{\Delta t} \qquad V = I \cdot R \qquad R = \rho\left(\frac{L}{A}\right)$$

$$P = I \cdot V \qquad P = I^2 R \qquad P = \frac{V^2}{R}$$

$$R_{eq} = R_1 + R_2 + \ldots \qquad \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

$$C_{eq} = C_1 + C_2 + \ldots \qquad \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$$

$$I_{in} = I_{out} \quad (\textit{Junction Rule}) \qquad \mathcal{E} = \sum \Delta V \quad (\textit{Loop Rule})$$

$$q(t) = C\mathcal{E}\left(1 - e^{-t/\tau}\right) = Q\left(1 - e^{-t/\tau}\right) \qquad I(t) = \left(\frac{\mathcal{E}}{R}\right)e^{-t/\tau} \qquad \tau = RC$$

Some useful unit conversions and constants may be:

$e = 1.60 \times 10^{-19}$ C	$k = 8.99 \times 10^{9}$ N m^2/C^2	$\epsilon_o = 1/(4\pi k) = 8.85 \times 10^{-12}$ C^2/(N m^2)

Good luck, and May the Force be with you!

⟨1⟩ **[30 pts total]** TEST CHARGES!

You carry a $q = 10^{-9}$ C test charge around in your pocket for exploring electricity you encounter. One day while leaving physics class, you come across an electric blob with a charge $Q = 1.5$ C. Pulling out your test charge, you probe the blob from 2.7 meters away.

(a) **[10 pts]** What force is felt by your test charge?

(a) 1.85 N	(b) 5.0 N	(c) 1.85×10^{-9} N	(d) 2.0 N

$$F = \frac{kq_1q_2}{r^2} = \frac{(8.99\times10^9 \frac{Nm^2}{C^2})(10^{-9}C)(1.5C)}{(2.7m)^2} = 1.85N$$

(b) **[5 pts]** What electric field does the test charge see?

(a) 1.85 N/C	(b) 5.0×10^9 N/C	(c) 1.85×10^9 N/C	(d) None

$$E = \frac{F}{q_1} = \frac{1.85N}{10^{-9}C} = 1.85\times10^9 \frac{N}{C}$$

(c) **[10 pts]** What potential energy does your test charge have?

(a) 1.85 J	(b) 5.0 J	(c) 5.0×10^{-9} J	(d) 2.0 J

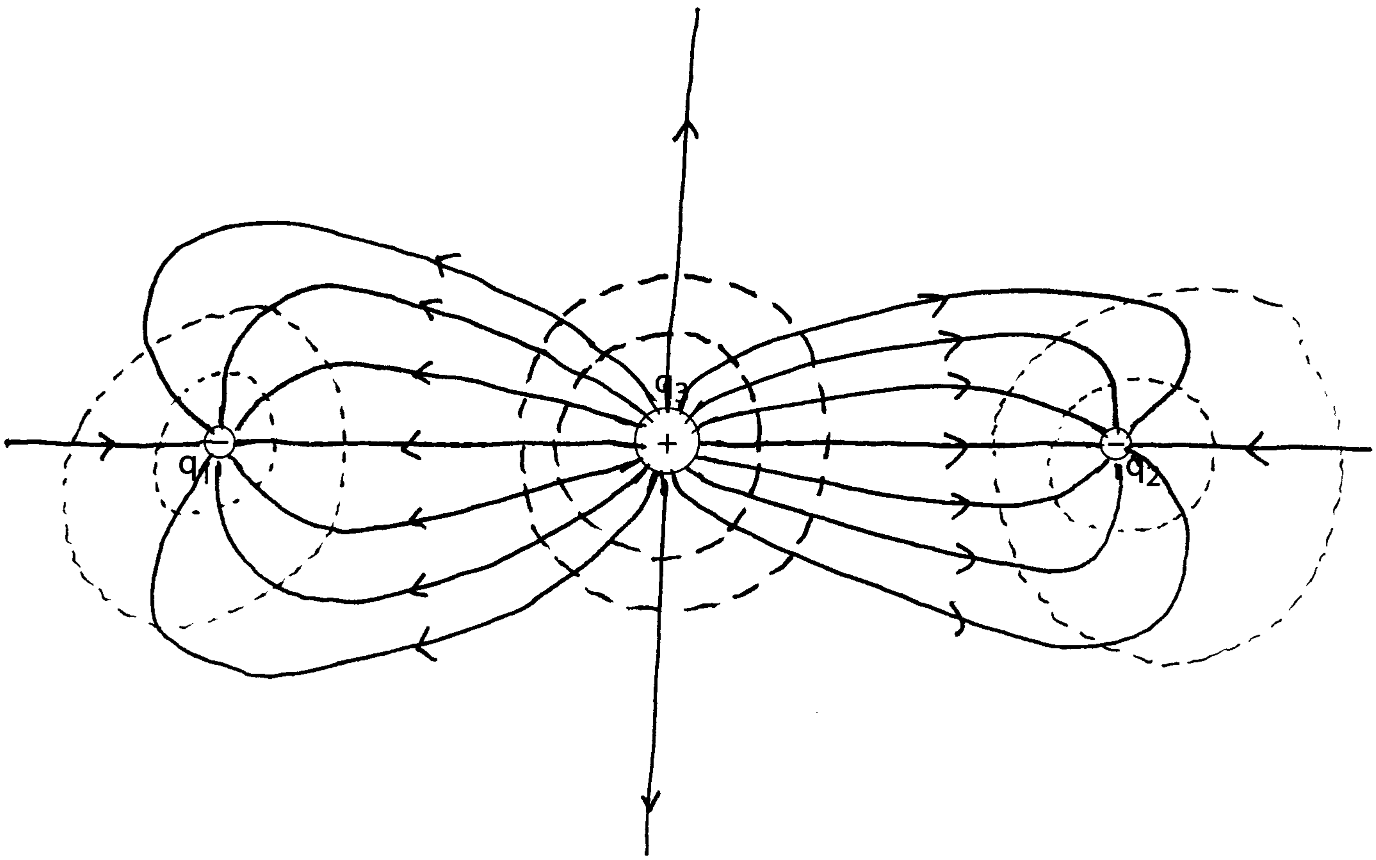
$$U_E = \frac{kq_1q_2}{r} = \frac{(8.99\times10^9 \frac{Nm^2}{C^2})(10^{-9}C)(1.5C)}{(2.7m)} = 5.0J$$

(d) **[5 pts]** What potential is seen by your test charge?

(a) 3.3 J/C	(b) 1.85×10^9 J/C	(c) 1.3 J/C	(d) 5.0×10^9 J/C

$$V = \frac{U_E}{q_1} = \frac{5.0J}{10^{-9}C} = 5.0\times10^9 V = 5.0\times10^9 \frac{J}{C}$$

⟨2⟩ **[20 pts total]** Consider the arrangement of charges shown below. Draw the electric field diagram and equipotentials for the charges below if $q_1 = q_2 = -q$ and $q_3 = +2q$. Be sure to indicate where the potential is negative and where it is positive.



Negative equipotentials arond (−) charges
Positive equipotentials around (+) charges
All equipotentials (and) ⊥ to E fields (→)

⟨3⟩ **[30 pts total]** SPARK PLUGS!

Spark plugs in cars generate sparks that jump across two metal terminals separated by a small distance; the spark ignites the fuel in the vicinity of the spark plug, and the small explosion drives the pistons in your car. This is what makes your car 'go'. The spark plug in my beloved Yugo has a 0.635 mm gap. An electric field of 3.0×10^6 V/m is required to ignite the fuel.

(a) **[10 pts]** What potential difference is needed to ignite the fuel?

Potential is related to E-field by:

$$V = E \cdot d = (3.0 \times 10^6 \tfrac{V}{m})(0.635 \times 10^{-3} m)$$

$$= \boxed{1905\,V}$$ (ANS)

(b) **[10 pts]** What happens to the electric potential across the spark plug if the gap is increased? *Explain.* [Assume the electric field remains constant.]

Since $V = E \cdot d$ if $E = \text{CONST}$ then if d increases V must increase

if d decreases V must decrease

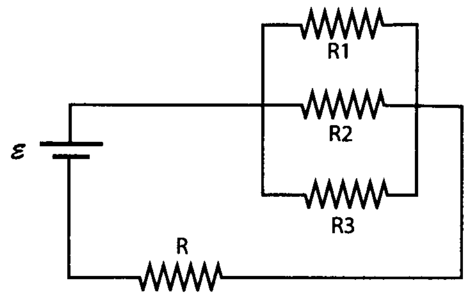
(c) **[10 pts]** When your spark plugs go out (the gap size grows as the metal in the plug deteriorates), the required potential to make a spark changes. If the gap has grown to 1.27 mm, what is the electric field when 3600 V is applied across the spark plug? Does the plug ignite the fuel?

E-field is related to potential by

$$V = E \cdot d \rightarrow E = \frac{V}{d} = \frac{3600\,V}{1.27 \times 10^{-3} m} = \boxed{2.8 \times 10^6 \tfrac{V}{m}}$$ (ANS)

Gas will <u>NOT</u> ignite. I'm stranded and can't get to school to give you the midterm! :)

⟨4⟩ **[30 pts total]** You decide that combining your excellent physics education in electricity with your own entrepreneurial ambitions will be the best way to become independently wealthy. To this end, you invent a simple hand-warmer for skiing which dissipates energy through a series of resistors, as shown below.



Here, $R_1 = 12\Omega$, $R_2 = 4\Omega$ and $R_3 = 19.5\Omega$.

(a) **[10 pts]** What is the equivalent resistance of resistors R_1, R_2 and R_3?

R_1 R_2 and R_3 are in parallel so:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{12\Omega} + \frac{1}{4\Omega} + \frac{1}{19.5\Omega} = \frac{0.385}{\Omega}$$

So// $\boxed{R_{eq} = 2.6\Omega}$ (ANS)

(b) **[10 pts]** The battery provides an EMF of $\mathcal{E} = 24.0V$. If the current through the battery is 2.5 A, what is the size of the resistor R?

The battery sees a SINGLE resistance for the circuit, which is R in series with Req, or: $R_B = R + R_{eq}$ = resistance battery sees

Using Ohm's Law:

$$V = IR_B \rightarrow \mathcal{E} = IR_B = I(R + R_{eq}) \rightarrow R + R_{eq} = \mathcal{E}/I \rightarrow R = \frac{\mathcal{E}}{I} - R_{eq}$$

So// $R = \frac{24.0\text{ V}}{2.5\text{ A}} - 2.6\Omega = 9.6\Omega - 2.6\Omega = \boxed{7.0\Omega}$ (ANS)

(c) **[10 pts]** How much power is dissipated by the resistor R?

The resistor sees the same current as the battery, so power is:

$$P = I^2R = (2.5A)^2(7.0\Omega) = \boxed{43.8W}$$ (ANS)

(5) **[30 pts total]** SPOCK-O-TRON 8000

Now that you have taken PHYS 2020, you can be trusted to use *real physics equipment* for a variety of purposes, like heating up your lunch.

Throw out your silly microwave, and consider using a linear particle accelerator to heat your food. The Spock-o-tron 8000 accelerates protons from rest to $v = 2 \times 10^8$ m/s. Protons have a mass of $m = 1.673 \times 10^{-27}$ kg.

(a) **[15 pts]** What is the potential difference V in the accelerator?

At one end (start) the protons have potential energy: $U_E = \frac{1}{2} q V$

At the other (end) the protons have all kinetic energy: $K_E = \frac{1}{2} m v^2$

Conserving energy: $U_{Ei} = K_{Ef}$

so// $\frac{1}{2} q V = \frac{1}{2} m v^2 \Rightarrow V = \frac{1}{q} m v^2$

so// $V = \frac{(1.673\times10^{-27} kg)(2\times10^{8} m/s)^2}{(1.60\times10^{-19} C)} \doteq \boxed{4.2\times10^{8} V}$ (ANS)

(b) **[10 pts]** It takes 1.3×10^5 J of energy to heat up a piece of lasagne for lunch. If you heat your piece by putting it at the end of the accelerator and bombarding it with protons, what current I is required to heat your lunch up in 45 seconds?

The POWER needed is $P = \frac{\Delta E}{\Delta t} = \frac{1.3\times10^5 J}{45 s} = 2890 W$

Power is related to current and voltage by: $P = IV$

so// $I = \frac{P}{V} = \frac{2890 W}{4.2\times10^8 V} \doteq \boxed{6.9\times10^{-6} A}$ (ANS)

(c) **[5 pts]** What power must the accelerator sustain to heat your lasagne in the prescribed time?

As noted above: $P = \frac{\Delta E}{\Delta t} = \frac{1.3\times10^5 J}{45 s} \doteq \boxed{2890 W}$. (ANS)