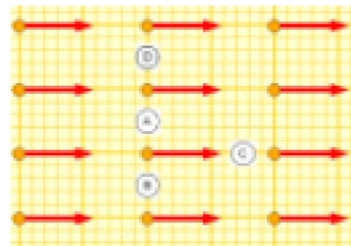
University of Maryland
Department of Physics

Physics 132
Spring 2014 **Sample exam 2 problems** **11 April 2014**

1. (25 points) *For the ranking questions below, use ">" to mean greater than and "=" to mean equal. Do* *<u>not</u>* *use "<" signs. Your answer should be a string of letters that looks something like E = F > G > H, meaning E and F are equal and bigger than G, and G is bigger than H. You, of course, should use the letters ABCD and the appropriate ranking.*

1.1 A negative charge might be placed at one of four spots in a region where there is a uniform electric field as shown by the red arrows. Rank the magnitude of the electrostatic field, *E*, felt by the charge at positions A, B, C, and D. (5 pts)



It's a uniform electric field! A = B = C = D.

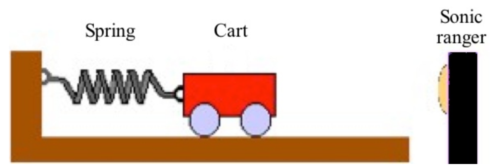
1.2 Rank the values of the electrostatic potential of the negative charge placed at the indicated positions. (5 pts)

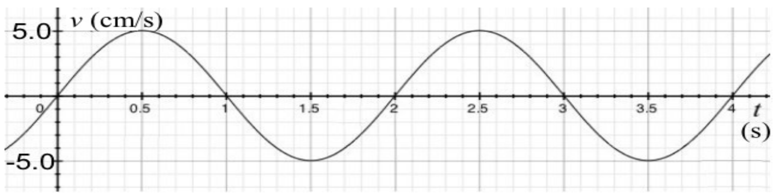
The electric field points from higher to lower potential. Perpendicular to the electric field, there is no change in potential. Therefore, A = B = D > C.

1.3 If the grid spacing on the graph is that 1 large box corresponds to 1 nm, and if the electric field displayed has a value of 10^7 N/C (= 10 milliVolts/nanometer), how much work would it take to move a single OH^- ion from position C to position D? (Show your work briefly at the left and put your answer in the box at the right.) (5 pts)

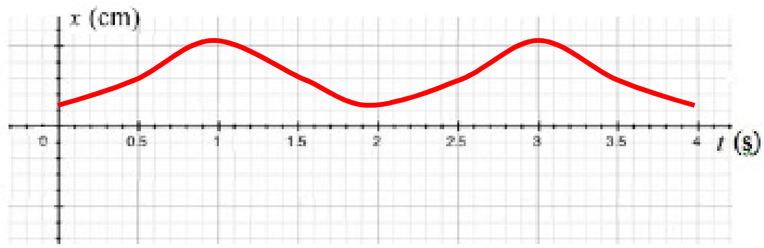
It takes no work to move perpendicular to the electric field; it only takes work to move against the electric field (i.e. the horizontal direction in this case). The horizontal distance from C to D is 1.5 nm, so the potential difference is Ed = 15 mV. The work it takes is $qV = (1.6 \times 10^{-19}$ C)$(1.5 \times 10^{-3}$ V) $= 2.4 \times 10^{-22}$ J, or we could express this as 1.5×10^{-3} eV.

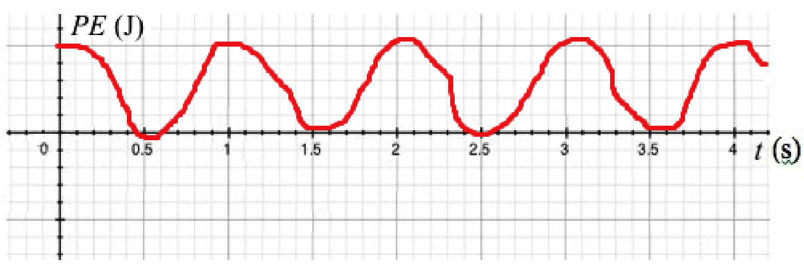
2. A sonic ranger is measuring the position of a wheeled cart connected to a spring as shown in the figure at the right. The cart of mass 200 g is pulled to the right and released. The ranger starts taking data a little bit later. The computer screen shows a graph of the cart's velocity that looks like this.





2.1 On the graphs below, sketch what the position of the cart and the potential energy stored in the spring would look like. (Be qualitative in the vertical plot but careful in the horizontal.)





These are rough, hand-drawn graphs (like you'll do on the exam). The vertical values are arbitrary, but the horizontal values (time) match the times given in the velocity vs. time graph above. We see in the velocity graph that the velocity is 0 at time 0, which means that at time 0, the cart must be starting at one of the extreme points (either the maximum x or the minimum x). And we see that the velocity is positive immediately after time 0, so we know that the cart must have started at the minimum x position (so that it could move in the positive direction after that). We can generate the rest of the position vs. time graph using this information. We see that $v = 0$ again at $t = 1$ s, so that's when the cart reaches the other extreme position (this time, the maximum), and so forth at $t = 2$ s, 3 s, etc. Note that the x position (as measured by the sonic ranger) is always positive, so the maximum and minimum x are both positive values.

We can generate the potential energy graph using the position graph, because we know that the potential energy is proportional to the **square** of the distance that the spring is stretched or compressed from the equilibrium position. When the spring is at the equilibrium position, we can define the PE to be 0. When the spring is at the maximum **or** minimum position, the PE is at its maximum (because the square is always positive).

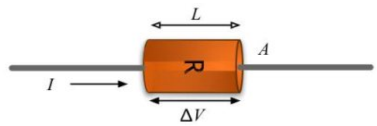
2.2 From the information given, can you tell what the maximum and minimum values of the x oscillation are? If you can, explain how you would calculate it (but don't). If you can't, explain why not.

No, we can't. From the velocity data we know how much the x is **changing**, but we don't know what position it's starting at. However, we can calculate the distance between the maximum and minimum by integrating the velocity. The maximum excursion in position is the maximum excursion in velocity divided by the angular frequency. The angular frequency can be determined by reading the period from the graph. It is 2 seconds. Angular frequency there for is pi radians per second (2 pi/T)

2.3 From the information given, can you tell what the maximum and minimum values of the PE oscillation are? If you can, explain how you would calculate it (but don't). If you can't, explain why not.

Yes we can! The total energy of the system is conserved. When the spring is at the equilibrium position, we have defined PE = 0, and the KE is equal to the total energy. When the spring is at the maximum or minimum position, KE = 0 (since velocity is 0), and the PE is equal to the total energy. So the maximum value of the PE is equal to the maximum value of the KE, which is equal to $mv^2/2$ when the velocity is at a maximum. We know the mass of the cart (given in the problem), and we can read the maximum velocity off of the velocity vs. time graph, so we can use these to find the maximum KE, which is equal to the maximum PE. And the minimum PE is 0 (when the spring is at the equilibrium position).

3. A steady current is flowing through a resistor that is made out of an electrically uniform substance. It is well described by Ohm's law. The resistor has the dimensions and electrical measurements as indicated in the figure.



3.1 Suppose that the original resistor is replaced by a resistor of the same length and identical material but twice the cross sectional area. Further suppose that the potential drop across the resistor is the same as for the original. The current through the new resistor will be (5 pts)

(a) The same as for the original resistor.
(b) Twice as big as for the original resistor.
(c) Half as big as for the original resistor.
(d) Some other multiple of the original current.
(e) You can't tell from the information given.

Doubling the cross sectional area allows twice as much current to get through (for the same potential difference).

3.2 Suppose that the original resistor is replaced by a resistor of the same cross sectional area and identical material but twice the length. Further suppose that the potential drop across the resistor is the same as for the original. The current through the new resistor will be (5 pts)

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Doubling the length of the resistor doubles the resistance, which results in half the current (for the same potential difference).

4. Consider the inside and outside of a cell, The outside starts off with a 1 mM (milli-Molar) concentration of NaCl and a 2mM concentration of KCl. The inside of the cell initially has a 10 μM (micro-Molar) concentration of NaCl and a 1 μM concentration of KCl. Now we add Na^+ ion channels to the membrane that let Na^+ freely pass from side to side.

$$\Delta V = \frac{k_B T}{q} \ln\left(\frac{c_2}{c_1}\right)$$

4.1 The Nernst potential can be calculated from the following equation:

a. Calculate the Nernst potential of Na^+.

We can calculate the Nernst potential for each ion using the equation above. At room temperature, $k_B T \approx 0.025$ eV. The charge of each ion is 1 elementary charge, so $k_B T/q \approx 0.025$ V. Then we can plug in the ratio of the concentrations on the two sides of the membrane to find the Nernst potential. For Na^+, there is 1 mM on the outside and 10 μM on the inside, so we get 0.115 V.

b. Calculate the Nernst potential of Cl^-.

The concentration of Cl^- is 3 mM on the outside and 11 μM on the inside, so we plug this in and get -0.14 V (opposite sign because the charge is negative!).

c. Calculate the Nernst potential of K^+.

The concentration of K^+ is 2 mM on the outside and 1 μM on the inside, so we plug this in and get 0.19 V.

4.2 Which of the following statements are true about the system after the Na^+ channel is open

A. Some Cl^- accumulates on the membrane on the side with higher Cl^- concentration

B. Some Cl^- accumulates on the membrane on the side with lower Cl^- concentration

C. No Cl^- accumulates at the membrane

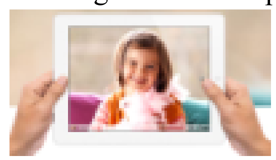
D. Some K^+ accumulates on the membrane on the side with higher K^+ concentration

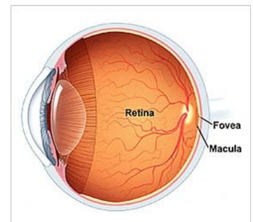
E. Some K^+ accumulates on the membrane on the side with lower K^+ concentration

F. No K^+ accumulates

When the Na^+ channel is open, Na^+ ions will flow into the cell (towards lower concentration). This means that the inside of the cell will get a net positive charge, and the outside will get a net negative charge. This results in an electric field pointing outwards. As a result, the K^+ ions on the inside of the cell will be attracted to the negative outside (and accumulate on the membrane), and the Cl^- ions on the outside of the cell will be attracted ot the positive inside (and accumulate on the membrane).

5. Apple is advertising its new 3 megapixel display iPad as having a "retinal display", i.e., the screen contains 3 x 10^6 dots that show color and is claimed to have as high a density of display pixels as your retina has detector pixels (cones). Let's see how good this statement is by estimating the number of pixels in your retina. Only consider the cone cells that detect color.





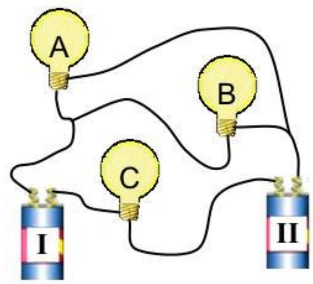
The drawing at the right shows how much of the eye is covered by the retina. The distance between cones on the retina is typically about 2-3 microns (micrometers). Compare the density (number/cm^2) of cones on your retina and on the iPad. Is "retinal display" a reasonable claim for the new iPad? *Be sure to clearly state your assumptions and how you came to the numbers you estimated, since grading on this problem will be mostly based on your reasoning, not on your answer.*

If the distance between cones on the retina is 2-3 μm, this means there are about 4000 cones per centimeter. Square this, and we find that the density of cones on the retina is about 2 x 10^6 cones per cm^2.

The dimensions of an iPad screen are about 24 x 17 cm (but you'll make your own estimates), so the area is about 400 cm^2. Therefore the density of pixels on the iPad screen is on the order of 10^4 pixels per cm^2.

Therefore, NO, "retinal display" is not a reasonable claim! The density of pixels on the iPad is still significantly less than on the retina. How many Pinochios?

5. In the figure at the right is shown a circuit with two identical batteries and three identical resistors (bulbs). The batteries are shown so that the anode (positive terminal) is on the right of each battery. If one of these batteries were to be directly connected to one of these bulbs, it would light the bulb brightly.



For the following items, select the item that best completes the sentence and enter it in your answer sheet. If more than one answer is correct, give them all. Briefly explain your answers.

5.1 When the set of batteries and bulbs are connected as shown
- A. none of the bulbs will be lit.
- B. only one of the bulbs will be lit.
- C. all of the bulbs will be lit equally brightly.
- D. all of the bulbs will be lit but they will not be equally bright.
- E. you cannot tell which bulbs will be lit from the information given.

All of the current goes through bulb C, but the current splits between A and B.

5.2. The current through bulb C
- A. equals zero.
- B. is the same as through the other two bulbs.
- C. is greater than through either of the other bulbs.
- D. is less than through either of the other bulbs.
- E. is the same as the current in battery I.
- F. is the same as the current in battery II.
- G. cannot be determined from the information given.

See above.

5.3. The potential drop across bulb B
- A. equals zero.
- B. is the same as that across bulb A.
- C. is the same as that across bulb C.
- D. is the same as that across one of the batteries.
- E. is double that across one of the batteries.
- F. cannot be determined from the information given.

Bulbs A and B are connected in parallel. They are connected across the same two points in the circuit; therefore the potential difference across them is the same.