University of Alabama
Department of Physics and Astronomy

PH 102-1 / LeClair Summer II 2008

Exam I Solutions

1. An electron is released a short distance above the surface of the Earth. A second electron directly below it exerts an electrostatic force on the first electron just great enough to cancel the gravitational force on it. How far below the first electron is the second?

- ■ 5.1 m
- □ 7.5 m
- □ 10.2 m
- □ 2.5 m

What we are really asking is, "at what distance below a proton would the upward force on an electron equal the electron's weight?"

To determine that, all we need to do is write down the two forces and balance them. The electron has mass m_e and charge $-e$, the proton has charge e, and the distance between them we'll call d. Our origin will be at the proton's position:

$$m_e g - \frac{k_e e\,(-e)}{d^2} = 0$$

$$d^2 = \frac{k_e e^2}{m_e g}$$

$$d = \sqrt{\frac{k_e e^2}{m_e g}} = \sqrt{\frac{\left(9\times 10^9\,\mathrm{N\cdot m^2/C^2}\right)\left(1.6\times 10^{-19}\,\mathrm{C}\right)^2}{\left(9.1\times 10^{-31}\,\mathrm{kg}\right)\left(9.8\,\mathrm{m/s^2}\right)}}$$

$$d \approx \sqrt{26\,\frac{\mathrm{N\cdot m\cdot s^2}}{\mathrm{kg}}} = \sqrt{26\,\frac{(\mathrm{kg\cdot m/s^2})\cdot\mathrm{m\cdot s^2}}{\mathrm{kg}}}$$

$$\Longrightarrow \quad d \approx 5.1\,\mathrm{m}$$

2. A point charge q is located at the center of a spherical shell of radius a that has a charge $-q$ uniformly distributed on its surface. Find the electric field for a point a distance $r > a$ from the center of the shell (*i.e.,* outside the sphere).

- □ $E = \frac{k_e q}{r^2}$
- □ $E = \frac{k_e q}{4\pi r^2}$
- ■ $E = 0$
- □ $E = \frac{k_e q^2}{r^2}$

The simplest way to solve this one is with Gauss' law. First, Gauss law told us that any spherically symmetric charge distribution behaves as a point charge. Second, Gauss law tells us that the electric flux out of some surface depends only on the enclosed charge. If we draw a spherical surface of radius r and area A enclosing the shell *and* the point charge, centered on the center of the conducting sphere, the total enclosed charge is that of the shell plus that of the point charge: $q_{\text{encl}} = q + (-q) = 0$. If the enclosed charge is zero for any sphere drawn outside of and enclosing the spherical shell, then the electric field for all points outside the spherical shell.

3. Calculate the speed of a proton that is accelerated from rest through a potential difference of 130 V.

- □ $3.21\times 10^4\,\mathrm{m/s}$
- □ $7.9\times 10^4\,\mathrm{m/s}$
- □ $6.76\times 10^6\,\mathrm{m/s}$

- ■ 1.58×10^5 m/s

4. A parallel-plate capacitor is disconnected from a battery, and the plates are pulled a small distance further apart. Which quantities increase, which decrease, and which stay the same?

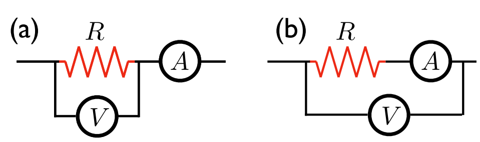
- ☐ C, Q decrease, ΔV increases, energy stays the same
- ■ C decreases, Q stays the same, ΔV and energy increase
- ☐ $\Delta V, Q$ decrease, energy stays the same, C increases
- ☐ energy decreases, C, Q stay the same, ΔV increases

5. Two resistors, A and B, are separately connected across identical batteries. The resistance of A is twice that of B. Which resistor dissipates more power?

- ☐ resistor A
- ■ resistor B
- ☐ both resistors dissipate the same power
- ☐ more information is needed.

6. Referring to the circuit below, which of the following must be true? In both circuits, we attempt to measure a resistor R by separately measuring the current and voltage and using Ohm's law. Assume both meters have internal resistance.

- ☐ Circuit **a** overestimates R, circuit **b** underestimates it.
- ■ Circuit **a** underestimates R, circuit **b** overestimates it.
- ☐ Both circuits overestimate R.
- ☐ Both circuits underestimate R.



In circuit **(a)**, at least a little current goes through the voltmeter, which reduces the current through the resistor slightly. Since it is in parallel with the resistor, it does at least measure the proper voltage. The ammeter measures the total current, however, since it is outside of the parallel circuit formed by the voltmeter and resistor. This means that the apparent resistance - the measured voltage divided by the measured current - will be a little to *low*, since the measured current is higher than the actual value.

What about circuit **(b)**? In this case, the ammeter reads exactly the current through the resistor, since they are in the same branch of the circuit. The voltmeter, however, how reads the potential difference across the resistor *and* that across the internal resistance of the ammeter. It will always read an anomalously large voltage, which means it will systematically *overestimate* the resistance.

7. If the current carried by a conductor is doubled, what happens to the electron drift velocity?

- ☐ it is halved
- ☐ it remains the same
- ■ it is doubled
- ☐ it quadruples
- ☐ it decreases by four times

8. A battery having an ideal voltage of 11.00 V delivers 117 mA when connected to a 67.0 Ω load. What is the internal resistance of the battery?

- ☐ 9 Ω
- ☐ 83 Ω
- ■ 27 Ω
- ☐ 54 Ω

9. A sphere the size of a basketball is charged to a potential of −1000 V. About how many extra electrons are on it, per cm^2 of surface? A basketball has a radius of ∼ 12 cm.

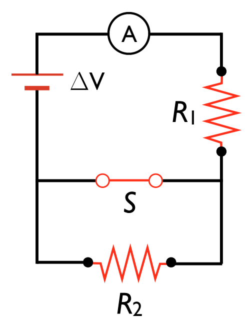
- ■ 3×10^7
- ☐ 1×10^8
- ☐ 5×10^4
- ☐ 7×10^5

10. The basic rules we have used for analyzing circuits are: **(1)** the sum of voltage sources and drops around a closed circuit loop is zero, and **(2)** the amount of current entering a junction has to equal the amount of current leaving the junction. These rules result from two basic physical laws. What are they?

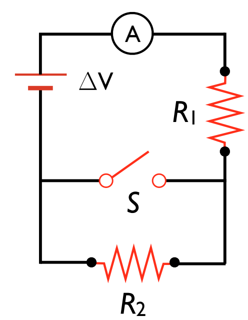
- ☐ Conservation of Energy and Charge Quantization
- ☐ Conservation of Energy and Conservation of Momentum
- ■ Conservation of Charge and Conservation of Energy
- ☐ Coulomb's law and Conservation of Charge

11. Refer to the figures at right. What happens to the reading on the ammeter when the switch S is opened? Assume the wires and switch are perfect, and have zero resistance.

- ☐ The reading goes up.
- ■ The reading goes down.
- ☐ The reading does not change.
- ☐ More information is needed.



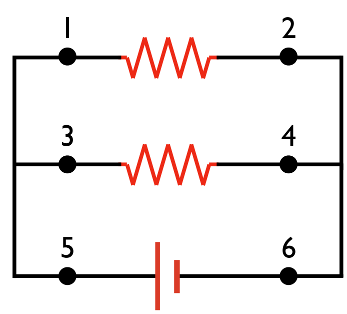
switch closed



switch open

12. Rank the currents at points 1, 2, 3, 4, 5, and 6 from *highest to lowest*. The two resistors are identical.

- ☐ 5, 1, 3, 2, 4, 6
- ☐ 5, 3, 1, 4, 2, 6
- ☐ 5=6, 3=4, 1=2
- ■ 5=6, 1=2=3=4
- ☐ 1=2=3=4=5=6



13. A parallel plate capacitor is shrunk by a factor of two in every dimension – the separation between the plates, as well as the plates' length and width are all two times smaller. If the original capacitance is C_0, what is the capacitance after all dimensions are shrunk?

- ☐ $2C_0$
- ■ $\frac{1}{2}C_0$
- ☐ $4C_0$
- ☐ $\frac{1}{4}C_0$

$\frac{1}{2}C_0$. The capacitance of a parallel plate capacitor whose plates have an area A and a separation d is $C = \frac{\epsilon_0 A}{d}$. If we imagine the plates to be rectangular of length l and width w, the area A is $A = lw$. Let the capacitance of the capacitor be $C_0 = \frac{\epsilon_0 lw}{d}$ *before* dimensions are shrunk. Once we reduce the length, width, and separation by two times, we have:

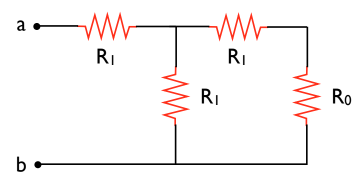
$$C = \frac{\epsilon_0 \left(\frac{1}{2}l\right)\left(\frac{1}{2}w\right)}{\left(\frac{1}{2}d\right)} = \frac{\epsilon_0 \frac{1}{2} lw}{d} = \frac{1}{2}C_0$$

It is easy to prove that if we chose, *e.g.,* circular plates, the answer would be the same – for any reasonable shape, the area goes down as the *square* of the dimensional decrease, while the separation just goes down as the factor itself.

14. It takes 3×10^6 J of energy to fully recharge a 9 V battery. How many electrons must be moved across the 9 V potential difference to fully recharge the battery?

- ☐ 1×10^{25} electrons
- ■ 2×10^{24} electrons
- ☐ 4×10^{12} electrons
- ☐ 8×10^{13} electrons

15. In the circuit at right, if R_0 is given, what value must the R_1 have for the equivalent resistance between the two terminals a and b to be R_0?



- ☐ $2R_0$
- ☐ $R_0/2$
- ☐ $2\sqrt{2}R_0$
- ■ $R_0/\sqrt{3}$

16. A spaceship moves away from earth at high speed. How do experimenters on earth measure a clock in the spaceship to be running? How do those in the spaceship measure a clock on earth to be running?

- ☐ slow; fast
- ■ slow; slow
- ☐ fast; slow
- ☐ fast; fast

17. The period of a pendulum is measured to be 3.00 in its own reference frame. What is the period as measured by an observer moving at a speed of $0.950c$ with respect to the pendulum?

- ☐ 6.00 sec
- ☐ 13.4 sec
- ☐ 0.938 sec
- ■ 9.61 sec

18. Suppose a (cylindrical) electrical wire is replaced with one of the same material, but having every linear dimension doubled - the length and radius are twice their original values. Does the new wire have:

- ☐ the same resistance
- ☐ twice the resistance

- ■ half the resistance
- □ four times the resistance
- □ one quarter the resistance

19. In a region of uniform electric field $\vec{\mathbf{E}}$, a charged particle experiences an acceleration $\vec{\mathbf{a}}$. If a second particle with twice the charge and twice the mass of the first particle enters that same region, it will experience an acceleration

- □ $\frac{1}{4}\vec{\mathbf{a}}$
- □ $\frac{1}{2}\vec{\mathbf{a}}$
- ■ $\vec{\mathbf{a}}$
- □ $2\vec{\mathbf{a}}$
- □ $4\vec{\mathbf{a}}$

20. Two particles are separated by a distance of 3.0 m; each exerts an electric force of 1.0 N on the other. If one particle carries 10 times as much electric charge as the other, what is the magnitude of the smaller charge?

- □ 10 pC
- ■ 10 μC
- □ 10 nC
- □ 10 kC