XF.4a **115**

PHYS-115(4) (Kaldon-26364) Name S O L U T I O N

WMU - Spring 2005

Final Exam - 200,000 points

Rev. 04/19/05 Tu.A5

State Any Assumptions You Need To Make – Show All Work – Circle Any Final Answers
Use Your Time Wisely – Work on What You Can – Be Sure to Write Down Equations
Short Answers Should Be Short! – Feel Free to Ask Any Questions

FINAL EXAM [FORM - A]

PHYS-115 (KALDON-4)

SPRING 2005

WMU

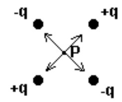
The Future Ends Thursday
19 May 2005 at 12:01am…

· STAR WARS EPISODE III: REVENGE OF THE SITH ·

(DR. PHIL HAS HIS TICKETS. DO YOU?)

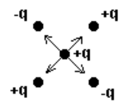
Getting a Charge Out of Physics (50,000 points)

1.) Four charges, $|q| = 6.00 \times 10^{-6}\ C$, are rigidly arranged in a square (L = 10.0 cm = 0.100 m) as shown. (a) Find the electric field vector, $\vec{E}_{total}$, at the center of the square of charges at point P.



E-fields cancel at center pairwise, so: $\boxed{\vec{E}_{total} = 0}$

(b) Another charge +q is placed in the center (point P). Find the force vector, $\vec{F}_{total}$, on the center charge due to the other four charges.



F_E cancel at center pairwise, too:

$$\vec{E}_{total} = 0$$
$$\vec{F}_{total} = 0 \quad OR$$
$$\vec{F}_{total} = q\vec{E}_{total} = 0$$

The Stanford Linear Accelerator, SLAC, is a real machine that takes electrons and accelerates them for most of a mile in vacuum up to speeds as great as 99.99% the speed of light. Consider an electron ($m_e = 9.11 \times 10^{-31}$ kg) in a constant electric field that starts from rest and ends up only at 1.00×10^8 m/s† after traveling in the $+x$ direction a distance of 1150 meters in 23.0 μsec. Using our old friend from the kinematic equations, *The Equation Without Time*, we find that $a = \frac{v^2}{2d}$ or $a = 4.35 \times 10^{12}\ m/s^2$. (c) What is the magnitude and direction of the force on the electron?

$$F = ma = \left(9.11\times10^{-31} kg\right)\left(4.35\times10^{12} m/s^2\right)$$
$$= 3.963\times10^{-19} N$$

F_E points in the same direction the electron accelerates: +x

(d) What is the magnitude and direction of the constant E-field required in part (c)?

$$F = ma = \left(9.11\times10^{-31} kg\right)\left(4.35\times10^{12} m/s^2\right)$$
$$= 3.963\times10^{-19} N$$
$$F_E = qE = -eE$$
$$E = \frac{F_E}{-e} = \frac{3.963\times10^{-19} N}{-1.602\times10^{-19} C} = -2.474 N/C$$

E points in the opposite direction the electron accelerates: -x

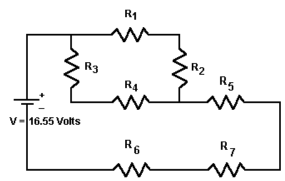
(e) What potential difference V would create the constant E in part (d)?

$$V = Ed = \left(2.474 N/C\right)\left(1150 m\right) = 2845 volts$$

† This is only one-third the speed of light, well below the threshold of where we have to worry about using Relativity.

An Initial Resistance to Measuring Your Capacity for Physics (50,000 points)

2.) All of the resistors in the circuit shown are $R = 100.\ \Omega$. Consider the three resistors along the right hand side (R_2, R_5, R_7) which, for the record, are *not* in parallel with each other. (a) Which of the three resistors sees the largest current? Why?



R_5 and R_7 are in series leading back to the battery, so they see the largest current.

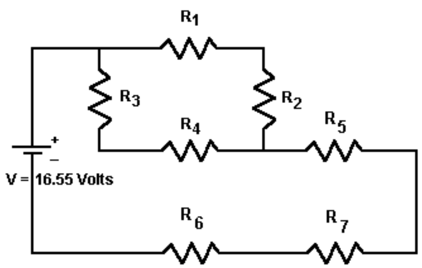
(b) Which of these three resistors generates the most heat? Why?

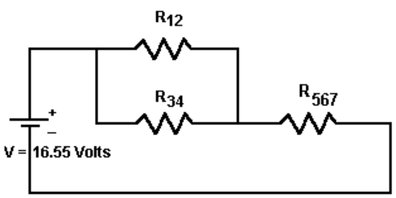
$P = I^2 R$; Since R_5 and R_7 see the most current and all the R's are identical then R_5 and R_7 generate the most heat.

(c) Find the equivalent resistance of this circuit. *Note: you don't have to do part (c) first to answer (a) or (b).*

1 and 2, 3 and 4, and 5-6-7 are in Series

12 and 34 are in Parallel

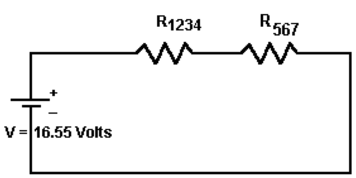


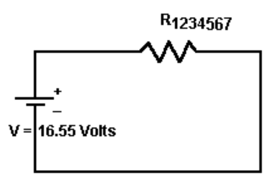


$$R_{12} = R_1 + R_2 = 100.\Omega + 100.\Omega = 200.\Omega$$
$$R_{34} = R_3 + R_4 = 100.\Omega + 100.\Omega = 200.\Omega$$
$$R_{567} = R_5 + R_6 + R_7 = 300.\Omega$$

$$\frac{1}{R_{1234}} = \frac{1}{R_{12}} + \frac{1}{R_{34}} = \frac{1}{200.\Omega} + \frac{1}{200.\Omega} = \frac{2}{200.\Omega}$$
$$R_{1234} = 100.0\Omega$$

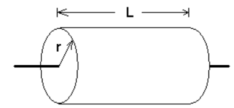
1-2-3-4 and 5-6-7 are in Series





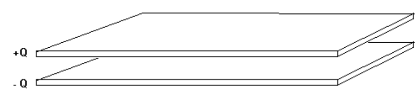
$$R_{total} = R_{1234} + R_{567} = 100.\Omega + 300.\Omega = 400.0\Omega$$

(d) A certain cylindrical resistor has a resistance R, a length L, a radius r, and a resistivity ρ. If we were to double the length, radius and resistivity, how would the new resistance R' differ from the original resistance R? Express your answer as $R' = m\,R$, where m is some multiplier which you will find.



$$R = \rho\frac{L}{A} \;;\; A = \pi r^2 \;;\; A' = \pi(2r)^2 = 4\pi r^2 = 4A$$
$$R' = 2\rho\frac{2L}{4A} = \rho\frac{L}{A} = R$$

(e) A parallel plate capacitor consists of plates that are 0.100 m × 0.275 m, separated by 0.0350 m of air and connected to a 12.0 V car battery. If we doubled all the numbers given in this problem, would the new capacitor hold more charge Q on the plates, or less?



$$C = \varepsilon_0\frac{A}{d} = \varepsilon_0\frac{lw}{d}$$
$$C' = \varepsilon_0\frac{2l(2w)}{2d} = \varepsilon_0\frac{4A}{2d} = 2C$$
$$Q = CV$$
$$Q' = C'V' = (2C)(2V) = 4CV = 4Q$$

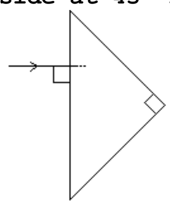
A Little Light Diversion (50,000 points)

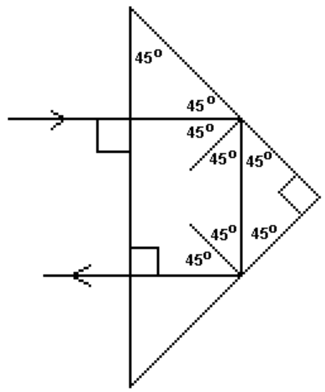
3.) (a) Find the critical angle θ_c for glass with an $n = 1.57$.

$$\theta_c = \sin^{-1}\left(\frac{1}{n_2}\right) = \sin^{-1}\left(\frac{1}{1.57}\right) = 39.6°$$

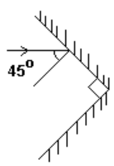
(b) Consider a 45°-45°-90° glass prism with an index of refraction $n = 1.57$, surrounded by air. A light ray comes in perpendicular to the long side, as shown. Follow the light ray, sketching it as it goes through the glass prism until it emerges back into the air. Calculate any of the angles which need to be calculated.

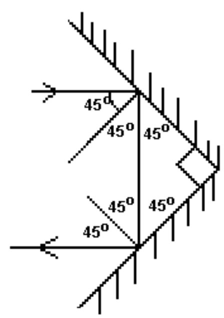
Incoming ray comes down normal line, 0°, so intersects angled side at 45° > 39.6°, so Total Internal Reflection… twice.





(c) Consider two flat mirrors placed together at right angles as shown. A light ray comes in to the top mirror at an angle 45° to the normal. Follow the light ray, sketching it as it bounces off both mirrors. Calculate any of the angles which need to be calculated.

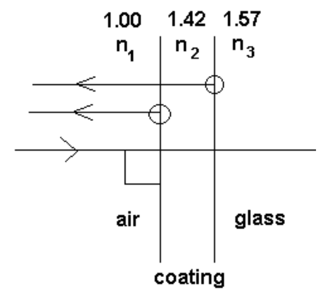




Gee – this corner reflector made from mirrors looks "just like" the mirror made from the T.I.R. inside the 45° prism.

(d) Suppose the light in part (b) comes from a little red LED laser pointer with a wavelength $\lambda = 656\ nm$ and we have placed an anti-reflection coating ($n_2 = 1.42$) on the glass ($n_3 = 1.57$). Find the thickness t of the anti-reflection coating.

Both reflections are low-to-high, so both are phase-shifted half a wavelength, and therefore doesn't change the problem.



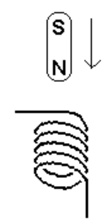
$$\lambda_m = \frac{\lambda}{n_m} = \frac{656nm}{1.42} = 462.0nm$$

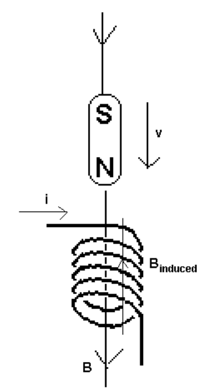
$$d = 2t = \frac{\lambda_m}{2}$$

$$t = \frac{\lambda_m}{4} = \frac{462.0nm}{4} = 115.5nm$$

(e) A shiny new rounded cylindrical Cow Magnet is dropped into a coil as shown. As the magnet enters the coil, indicate whether the induced magnetic field in the coil is pointing UP or DOWN and whether the induced current in the wire at the top of the coil is going to the LEFT or the RIGHT.

B-field from cow magnet is pointing down and increasing. The coil's response is to create an induced B-field pointing UP to try to cancel the increasing magnetic field. From the R.H.R. the induced current must be going to the RIGHT.





Relatively Speaking, This is The End (50,000 points)

4.) (a) We've already established in class what β corresponds to about a 10% difference between classical and relativistic physics. What if we were pickier and wanted to work at the 1% difference level? Determine the β, and find the speed v that $\gamma = 1.01$ corresponds to.

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$
$$\sqrt{1-\beta^2} = \frac{1}{\gamma}$$
$$1-\beta^2 = \frac{1}{\gamma^2}$$
$$\beta^2 = 1-\frac{1}{\gamma^2}$$
$$\beta = \sqrt{1-\frac{1}{\gamma^2}} = \sqrt{1-\frac{1}{(1.01)^2}} = 0.1404$$
$$v = \beta c = 0.1404c = (0.1404)(2.998\times 10^8 m/s)$$
$$= 42{,}090{,}000 m/s$$

(b) Bob is standing next to a 1.00 kilometer (1000 meters) stretch of road. Barbara zooms by at a speed v which gives her $\gamma = 1.01$. Find the time Bob says it takes Barbara to travel down the road and the time Barbara says it takes for the road to pass her by.

Bob sees the proper length.

$$d = v\,t$$
$$t = \frac{d}{v} = \frac{1000.m}{42{,}090{,}000m/s} = 0.00002376\sec$$

Barbara sees the improper length, or you can convert time to proper time.

$$L = \frac{L_p}{\gamma} = \frac{1000.m}{1.01} = 990.1m$$
$$t = \frac{d}{v} = \frac{990.1m}{42{,}090{,}000m/s} = 0.00002352\sec$$

OR

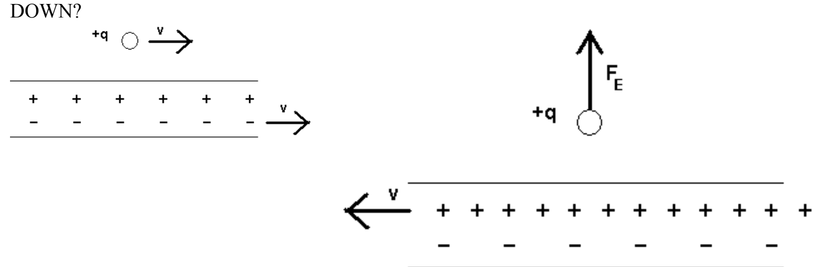
$$t = \gamma\, t_p$$
$$t_p = \frac{t}{\gamma} = \frac{0.00002376\sec}{1.01} = 0.00002352\sec$$

(c) An electron in the lithium ion Li^{+2} jumps from the $n = 5$ orbit to the $n = 4$ orbit. Find the radius of the new orbit and indicate whether a photon of light was ABSORBED or EMITTED by the electron to make the jump.

Lithium is Z = 3. And dropping to a lower *n* orbit emits light.

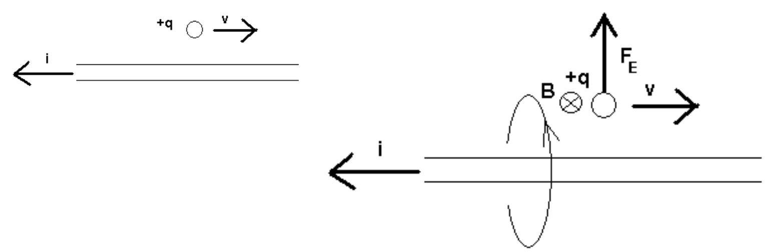
$$r_n = \frac{n^2}{Z}a_0 \;;\; r_4 = \frac{4^2}{3}(5.28\times 10^{-11}m) = 2.816\times 10^{-10}m$$

(d) *We've already repeatedly said that a current carrying wire has no net charge. But that's in classical physics. Consider the following situation*: Free electrons in the conductor and moving to the right at speed v, while their matching positive charges on the metal ions stay put. A positive charge $+q$ is near the wire and also moving to the right at the same speed v. From a relativistic point of view, the positive charge $+q$ is at rest with respect to the electrons, which sees the electrons as a line of charge with $\lambda = -Q/L$. But the line of positive charges – now they appear to be moving from the $+q$ charge's point of view. Does the spacing of the positive charges increase or decrease from the $+q$ charge's point of view? And does that make the wire appear to have a net POSITIVE or NEGATIVE charge? Which way does the electric force on the $+q$ charge point, UP or DOWN?



From the positive charge's point-of-view, it is at rest, and so the moving line of plus-charges appears to be Length Contracted, increasing the charge/length, giving the wire a net + charge.

(e) For a current carrying wire with the electrons going to the right, there is a positive current I going to the left. Which way does the magnetic force on the $+q$ charge point, UP or DOWN?



You've just seen the relativistic explanation for the magnetic force from a current carrying wire!