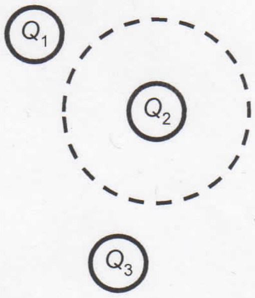
PH202-1G
Spring 2014

Mock exam IV

Print off your own copy of the mock exam and do your best to complete it before the mock exam session. We will not take any time during the mock exam session to complete the mock exam.

This mock exam will be most beneficial to you if you complete it under testing conditions. It should take you about 1 hour and 30 minutes to complete. Use the equation sheet provided by Dr. Wenger on Blackboard and the same calculator that you plan to use during the actual exam. If you get stuck, try to use the strategy in the document called "How to solve a physics problem" to help you. Do not use your book or notes from class until you have attempted the problems in the mock exam on your own at least once.

1. Three charges are arranged as shown in the figure to the right. Charges 1 and 2 have a positive charge, and charge 3 has a negative charge. What is the magnetic flux through the dashed surface around charge 2?



A. $\frac{Q_1 + Q_2 + Q_3}{\varepsilon_0}$

B. $\frac{Q_1 + Q_2 - Q_3}{\varepsilon_0}$

C. $\frac{Q_2}{\varepsilon_0}$

D. $\frac{Q_1 + Q_3}{\varepsilon_0}$

E. $\frac{Q_1 - Q_3}{\varepsilon_0}$

Gauss's law $\Phi_E = \frac{Q}{\varepsilon_0}$

We only consider charges inside of the surface.

Thus, we can ignore Q_1 and Q_3.

$\Phi_E = \frac{Q_2}{\varepsilon_0}$

2. A uniform electric field exists between two charged metal plates. An electron is released from rest between the plates and accelerates toward one plate, achieving a final speed v_0. Then, the space in between the plates is filled with chlorine gas, which has a dielectric constant κ of 16, and the battery attached to the plates is disconnected. A second electron is released from rest in the same location as the first. What is the final speed of the second electron compared to v_0? Assume that the gas does not interact with the electron during its movement.

A. The final speed is larger than v_0 by a factor of 16
B. The final speed is larger than v_0 by a factor of 4
C. The final speed is equal to v_0
D. The final speed is smaller than v_0 by a factor of 4
E. The final speed is smaller than v_0 by a factor of 16

Electrical potential energy ⇒ kinetic energy

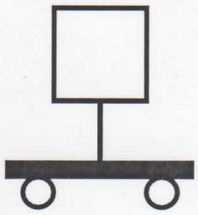
$qV = \frac{1}{2} m v^2$

First electron: $V_1 = V_0 = \sqrt{\frac{2qV}{m}}$

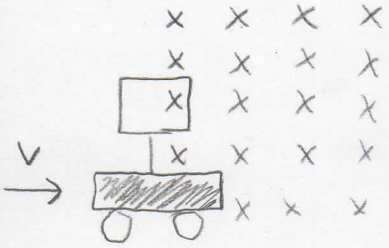
Dielectric constant increases capacitance by κ and thus reduces voltage by κ.

Second electron: $V_2 = \sqrt{\frac{1}{16} \frac{2qV}{m}} = \frac{1}{4}\sqrt{\frac{2qV}{m}} = \frac{1}{4} V_0$

3. A square loop of conducting wire is mounted on top of a cart as shown to the right. The cart is given a push so that it travels to the right with a constant speed over a frictionless surface. Then, the cart enters a region containing a uniform magnetic field pointing into the page. What happens to the cart during the time period between starting to enter the magnetic field and fully entering the magnetic field?



A. Current is induced in the clockwise direction, and the cart's speed increases
B. Current is induced in the counterclockwise direction, and the cart's speed increases
C. Current is induced in the clockwise direction, and the cart's speed decreases
D. Current is induced in the counterclockwise direction, and the cart's speed decreases
E. Current is induced in the clockwise direction, and the cart's speed does not change
F. Current is induced in the counterclockwise direction, and the cart's speed does not change

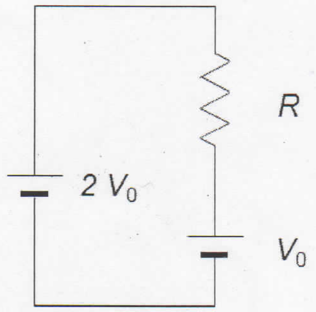


Lenz's law - induced emf will counteract the change in flux

As the cart moves into the region containing magnetic field, the flux increases into the page. Thus, the induced emf will produce magnetic field out of page, requiring that current is counterclockwise.

Current travels upward in the right side of the loop and feels a force to the left due to the magnetic field. Thus, the speed decreases.

4. ~~How much heat is~~ At what rate is heat generated by the resistor in the circuit depicted to the right?



A. $\frac{3\ V_0}{R}$

B. $\frac{V_0}{R}$

C. $\cancel{9 V_0^2 R}$ $\frac{9 V_0^2}{R}$

D. $\cancel{3 V_0^2 R}$ $\frac{3 V_0^2}{R}$

E. $\cancel{V_0^2 R}$ $\frac{V_0^2}{R}$

Heat is energy, and rate of heat generation is $\frac{\text{Energy}}{\text{Time}} = \text{Power}$

$$P = IV = \frac{V^2}{R}$$

Use Kirchhoff's loop rule : $\Sigma V = 0$

$$2V_0 - V_R - V_0 = 0$$

$$V_R = V_0$$

$$P = \frac{V_0^2}{R}$$

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5. You are designing an interface that needs to refract light at a boundary with water (refractive index 1.333) at incident angles up to 75°. What is the largest refractive index that can be used for the material at the interface?

   A. 0.725
   B. 1.288
   C. 1.380
   D. Any material can achieve this effect
   E. No material can achieve this effect

Critical angle must be greater than 75° to avoid total internal reflection.

$$n_1 \sin\theta_c = n_2 \sin 90°$$

$$n_1 = \frac{n_2}{\sin\theta_c} = \frac{1.333}{\sin 75°} = 1.380$$

6. A photon undergoes a collision with an electron and transfer some of its momentum to the electron. How does this collision change the photon?

   A. The photon has less energy
   B. The photon undergoes a wavelength shift toward blue light
   C. The photon undergoes a wavelength shift toward red light
   D. Both A and B
   E. Both A and C

$$E = hf = \frac{hc}{\lambda} = pc$$

If momentum decreases, then wavelength increases and energy decreases

7. Which of the following fusion reactions will produce the most energy? The mass of deuterium (^2_1H) is 2.0141 u, the mass of tritium (^3_1H) is 3.0161 u, and the mass of the helium atom is 4.0026 u. x and y are integers.

Reaction 1: $^2_1H + ^2_1H \longrightarrow ^4_2He + x\ ^1_0n$

Reaction 2: $^3_1H + ^3_1H \longrightarrow ^4_2He + y\ ^1_0n$

Balance atomic mass numbers

$2 + 2 = 4 + x \Rightarrow x = 0$

$3 + 3 = 4 + y \Rightarrow y = 2$

   A. Reaction 1 produces the most energy
   B. Reaction 2 produces the most energy
   C. Both reactions produce the same amount of energy

Energy of a Fusion reaction is given by $\Delta E = (\Delta m) c^2$

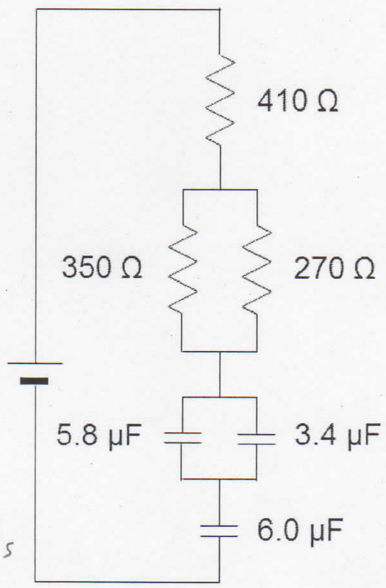
Which reaction has a larger mass defect?

Reaction 1: $\Delta m = 2M_{H-2} - M_{He} = [2(2.0141) - 4.0026]\,u$

Reaction 2: $\Delta m = 2M_{H-3} - M_{He} - 2M_n = [2(3.0161) - 4.0026 - 2(1.0087)]\,u$

$\Delta m_1 = 0.0256\,u > \Delta m_2 = 0.0122\,u$

8. Calculate the time constant of the RC circuit depicted to the right.



Time constant $\tau = RC$

$$R_{eq} = 410\ \Omega + \frac{350\ \Omega \times 270\ \Omega}{350\ \Omega + 270\ \Omega} = 562\ \Omega$$

$$C_{eq} = \left(\frac{1}{5.8\ \mu F + 3.4\ \mu F} + \frac{1}{6.0\ \mu F} \right)^{-1} = 3.6\ \mu F$$

$$\tau = R_{eq} C_{eq} = 562\ \Omega \times 3.6\ \mu F = 0.00204\ s$$

$$\boxed{\tau = 2.0\ ms}$$

9. Prove that the following two expressions for the energy density of an electromagnetic wave are equivalent.

$$u = \varepsilon_0 E^2 \qquad u = \frac{1}{\mu_0} B^2$$

We know that the fields in an electromagnetic wave are related by $E = cB$

The magnitude of the speed of light is $c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$

Thus: $u = \varepsilon_0 E^2 = \varepsilon_0 c^2 B^2 = \varepsilon_0 \frac{1}{\varepsilon_0 \mu_0} B^2 = \frac{1}{\mu_0} B^2$

10. Polonium-210 (atomic number 84) undergoes radioactive decay to form stable lead-206 (atomic number 82) in the presence of a magnetic field with strength 2.6 T. If the speed of the particle emitted from the radioactive decay is $3\times10^5\ \text{m}\cdot\text{s}^{-1}$, what is the radius of curvature of the path taken by the particle?

$${}^{210}_{84}Po \longrightarrow {}^{206}_{82}Pb + {}^{A}_{Z}X \qquad A = 210 - 206 = 4 \quad \text{and} \quad Z = 84 - 82 = 2$$

Thus, this is an alpha decay, and ${}^{A}_{Z}X$ is ${}^{4}_{2}He$ with a +2 charge

$$\frac{mv^2}{R} = qvB \Rightarrow R = \frac{mv}{qB} = \frac{2(M_{proton} + M_{neutron})\,v}{2\,e\,B}$$

$$R = \frac{(1.0073 + 1.0087)(1.6605\times10^{-27}\ kg)(3\times10^{5}\ m\cdot s^{-1})}{(1.6022\times10^{-19}\ C)(2.6\ T)} = 0.002412\ m$$

$$\boxed{R = 2.4\ mm}$$

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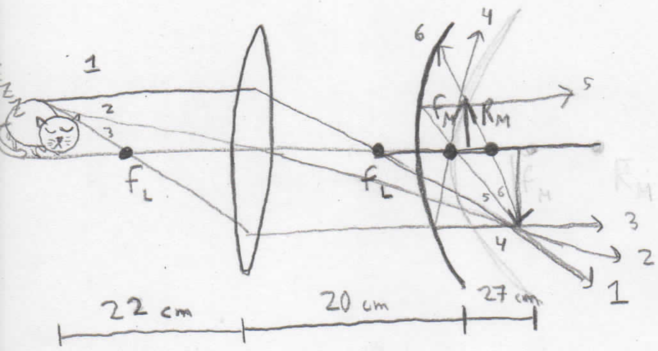
11. A converging lens with a focal length of 15 cm and a convex mirror with a radius of curvature of 12 cm are located 20 cm apart. A cat is napping 22 cm in front of the lens. Find the location of the image formed of the cat and the total magnification of the lens-mirror system.



For the converging lens:

$$d_i = \left(\frac{1}{f} - \frac{1}{d_o}\right)^{-1} = \left(\frac{1}{15\text{ cm}} - \frac{1}{22\text{ cm}}\right)^{-1} = 47\text{ cm}$$

The distance of this image from the mirror is

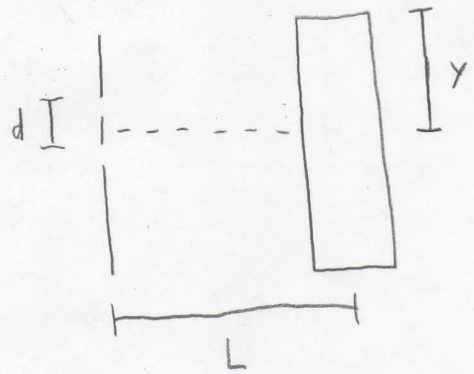
$$47\text{ cm} - 20\text{ cm} = 27\text{ cm}$$

This distance is behind the mirror, so object distance is negative. Focal length for a convex mirror is also negative.

$$d_i = \left(\frac{1}{-6\text{ cm}} - \frac{1}{-27\text{ cm}}\right)^{-1} = -7.7\text{ cm}$$

Total magnification is $M_T = M_L M_M = -\frac{d_{i-L}}{d_{o-L}} \times -\frac{d_{i-M}}{d_{o-M}} = \frac{47\text{ cm}}{22\text{ cm}} \times \frac{-7.7\text{ cm}}{-27\text{ cm}} = 0.61$

12. A replication of Young's double-slit experiment is performed with a separation of 75 μm between the slits. A screen 16 cm wide is set up 2 m away from the slits. When coherent light is shined on the slits, an interference pattern containing 13 bright fringes (including the central bright fringe) is observed. What is the wavelength of the light?



$d = 75\ \mu m \qquad L = 2\text{ m} \qquad y = \frac{16\text{ cm}}{2} = 8\text{ cm}$

13 fringes can be seen, including the central ($m=0$) fringe. Thus, $m = 6$

Using small angle approximations, $\sin\theta \approx \theta = \frac{m\lambda}{d}$ and $\tan\theta \approx \theta = \frac{y}{L}$

$$\lambda \approx \frac{dy}{mL} = \frac{(75\ \mu m)(8\text{ cm})}{6\ (2\text{ m})} = 5 \times 10^{-7}\text{ m}$$

$$\boxed{\lambda \approx 500\text{ nm}}$$

Note: Without the approximation, $\lambda = 499.6$ nm. Thus, the approximation is close enough.