Electricity and magnetism, 12-8-2016

The exam consists of two parts. The first part is multiple-choice. You only have to give the answer. Every correct answer is worth 0.25 points, up to a total of 2 points. The second part consists of open questions. For these you have to motivate your answers. Answers without motivation are considered as wrong. The total number of points for the open questions is 8; 0.5 per sub-question, except for 10b: 1 point.

<u>Multiple choice, 8 questions, 0.25 point per question</u>

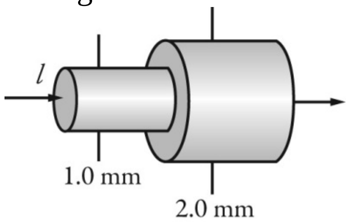
1) When two point charges are a distance *d* part, the electric force that each one feels from the other has magnitude *F*. In order to make this force twice as strong, the distance would have to be changed to
A) 2*d*.
B) $\sqrt{2}\,d$.
C) $d/\sqrt{2}$
D) *d*/2.
E) *d*/4.
Answer: C

2) Consider a spherical Gaussian surface of radius *R* centered at the origin. A charge *Q* is placed inside the sphere. To maximize the magnitude of the flux of the electric field through the Gaussian surface, the charge should be located
A) at $x = 0$, $y = 0$, $z = R/2$.
B) at the origin.
C) at $x = R/2$, $y = 0$, $z = 0$.
D) at $x = 0$, $y = R/2$, $z = 0$.
E) The charge can be located anywhere, since flux does not depend on the position of the charge as long as it is inside the sphere.
Answer: E

3) A negative charge, if free, will tend to move
A) from high potential to low potential.
B) from low potential to high potential.
C) toward infinity.
D) away from infinity.
E) in the direction of the electric field.
Answer: B

4) When two or more capacitors are connected in parallel across a potential difference
A) the potential difference across each capacitor is the same.
B) each capacitor carries the same amount of charge.
C) the equivalent capacitance of the combination is less than the capacitance of any of the capacitors.
D) All of the above choices are correct.
E) None of the above choices are correct.
Answer: A

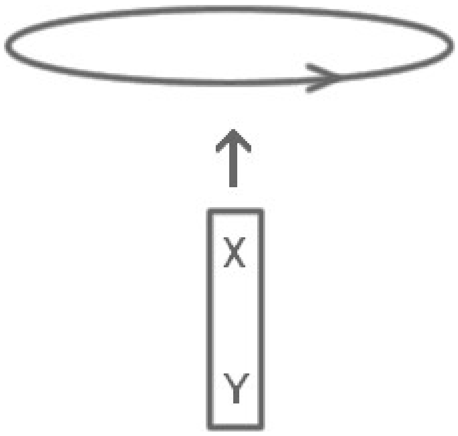
5) The figure shows two connected wires that are made of the same material. The current entering the wire on the left is 2.0 A and in that wire the electron drift speed is v_d. What is the electron drift speed in the wire on the right side?



A) $4v_d$
B) $2v_d$
C) v_d
D) $v_d/2$
E) $v_d/4$
Answer: E

6) A horizontal wire carries a current straight toward you. From your point of view, the magnetic field at a point directly below the wire points
A) directly away from you.
B) to the left.
C) to the right.
D) directly toward you.
E) vertically upward.
Answer: C

7) The figure shows a bar magnet moving vertically upward toward a horizontal coil. The poles of the bar magnets are labeled X and Y. As the bar magnet approaches the coil it induces an electric current in the direction indicated on the figure (counter-clockwise as viewed from above). What are the correct polarities of the magnet?

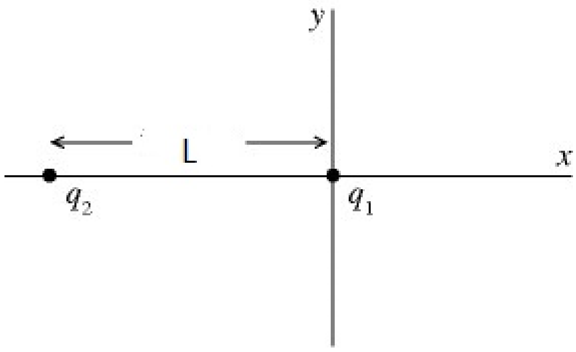


A) X is a south pole, Y is a north pole.
B) X is a north pole, Y is a south pole.
C) Both X and Y are north poles.
D) Both X and Y are south poles.
E) The polarities of the magnet cannot be determined from the information given.
Answer: A

8) The energy per unit volume in an electromagnetic wave is
A) equally divided between the electric and magnetic fields.
B) mostly in the electric field.
C) mostly in the magnetic field.
D) all in the electric field.
E) all in the magnetic field.
Answer: A

Open questions, 7 assignments

9) Assume two charges, q1 and q2, fixed on the horizontal axis, separated by a distance L. The charges are equal in magnitude but of opposite sign; q1 is positive and q2 is negative.



a- Can we put another particle with charge -Q on this axis such that it experiences no net force of the other two charges?
b- What is the strength of the electric field at x=L?

Answer:

a- Charges -Q and q_2 are of equal sign and will repel each other
Charges -Q and q_1 are of opposite sign and will attract each other.
A net force of 0 means that the forces of due to the q1 and q2 should be of equal magnitude, but opposite direction.

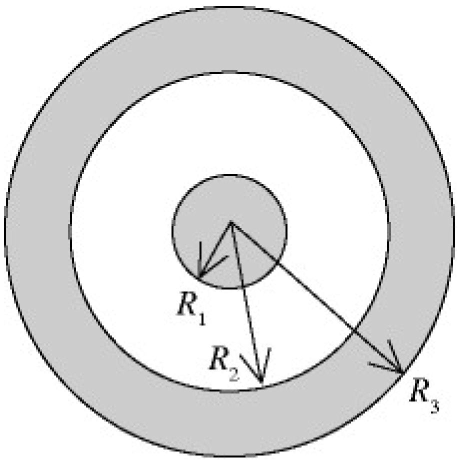
For a position between x=0 and x=-L these forces act in the same direction, and will not cancel each other.
For a position between x>0 or x<-L these forces act in opposite directions, but their magnitudes are different. They will not cancel each other.

There are no positions with a net force of 0.

b- $E(q1) = k\frac{q1}{L^2}$; $E(q2) = k\frac{q2}{(2L)^2} = -k\frac{q1}{(2L)^2}$; $E_{tot} = kq_1\frac{3}{4L^2}$;

10) Two concentric spheres are shown in the figure. The inner sphere is a solid nonconductor and carries a charge of +Q uniformly distributed over its outer surface. The outer sphere is a conducting shell that carries a net charge of -2Q µC. No other charges are present. The radii shown in the figure have the values R_1, R_2, and R_3. ($k = 1/4\pi\varepsilon_0$)

(a) Find the total excess charge on the inner and outer surfaces of the conducting sphere.
(b) Find the *magnitude* and *direction* of the electric field at the following distances *r* from the center of the inner sphere: (i) $r = 0.9R1$, (ii) $r = 0.9R2$, (iii) $r = 0.9R3$, (iv) $r = 2R3$.



Answer:

(a) The +Q charge of the inner sphere attracts -Q to the inner surface of the outer shell. The remaining -Q stays on the outer surface.

(b) Apply Gauss law for the different cases

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\epsilon_0} = E4\pi r^2; E = \frac{Q_{encl}}{4\pi r^2 \epsilon_0}$$

(i) $Q_{encl} = 0: E = 0$

(ii) $Q_{encl} = Q: E = \frac{Q_{encl}}{4\pi r^2 \epsilon_0}; radially\ outward$

(iii) $Q_{encl} = 0: E = 0$

(iv) $Q_{encl} = -Q: E = \frac{Q_{encl}}{4\pi r^2 \epsilon_0}; radially\ inwards$

11) A small sphere with radius carries +Q of charge distributed uniformly throughout its volume.

a) What is the potential difference, V_B - V_A, between point *B*, at a large distance R from the center of the sphere, and point *A*, which is at a distance 2R from the center of the sphere? (k = $1/4\pi\varepsilon_0$)
b) If we bring an electron from A to B, does its potential energy increase or decrease?

Answer:

a)

$$E = \frac{Q}{4\pi r^2 \epsilon_0}; V = -\int_R^{2R} \vec{E} \cdot \overrightarrow{dr} = -\frac{Q}{4\pi\epsilon_0}\int_R^{2R} \frac{1}{r^2} dr = -\frac{Q}{4\pi\epsilon_0}\left(\frac{1}{2R} - \frac{1}{R}\right) = \frac{Q}{4\pi\epsilon_0}\left(\frac{1}{R} - \frac{1}{2R}\right) = \frac{Q}{8\pi\epsilon_0 R}$$

b) Decrease. The potential increases from A to B, but the negative charge leads to a decrease of the potential energy.

12) A light bulb is connected to a 11-V source. What is the resistance of this bulb if it is a 121-W bulb?

Answer:

$$P = IV; V = IR \rightarrow P = \frac{U^2}{R} \rightarrow R = \frac{U^2}{P} = \frac{11^2}{121} = 1$$

13) A beam of electrons is accelerated through a potential difference of dV before entering a region having uniform electric and magnetic fields that are perpendicular to each other and perpendicular to the direction in which the electron is moving.

a) What is the speed with which the electrons enter the region?
b) If the magnetic field in this region has a value of B, what magnitude of the electric field is required if the particles are to be undeflected as they pass through the region?

Answer.

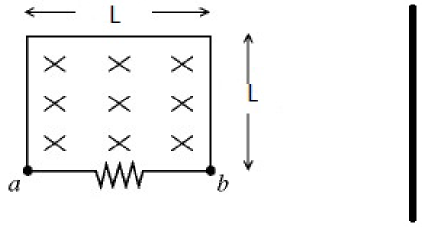
a) The electrons loose potential energy and gain and equal amount of kinetic energy

$$edV = \frac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2edV}{m}}$$

b) The magnetic and electric forces have to balance each other.

$$-eE = -evB \rightarrow E = \sqrt{\frac{2edV}{m}}B$$

14) As shown in the figure, a wire and a 10-Ω resistor are used to form a circuit in the shape of a square with sides L. The magnetic field enclosed by the circuit is due to a steady current I in the wire to the right side of the circuit. The distance of the wire to the centre of the circuit is L.



a) In which direction does the current I through the wire flow?
b) Hoe large is the *emf* between the points a and b of the circuit?

We now move the wire to the left with a velocity of L m/s.

c) Hoe large is the *emf* between the points a and b of the circuit after 1 second?
d) How large is the current in the circuit and in which direction does it flow between the point a and b?

Answers

a) The magnetic field through the circuit is directed into the paper. Right hand rule: I is downwards.
b) There is no changing flux: emf =0.
c)

$$at\, t=0:\Phi=\frac{\mu_0 IL}{2\pi}\ln\left(\frac{3L/2}{L/2}\right)=\frac{\mu_0 IL}{2\pi}\ln(3), see\, example\, 27.2$$

At t = 1 s the wire is in the middle of the circuit. To its left the magnetic field is pointed into the paper, to its right it is pointed outside the paper. There is no net magnetic field anymore, and therefore no flux.

$$emf = -(\Phi(t=1)-\Phi(t=0)))=\frac{\mu_0 IL}{2\pi}\ln(3)$$

d) The magnetic field due to the wire has decreased. The induced current will restore this. Right hand rule: current from b to a.

$$I = emf\ /\ R = mf\ /10$$

15) An radio signal is detected at an observation point R distant from a transmitter tower. Assume that the signal power is radiated uniformly in all directions and that radio waves incident upon the ground are completely absorbed. The measured power density is 100 W/m2.

a) We move the observation point to 2R. What happens the measured power density?
b) What is the significance of the assumption of absorption at ground?

Answer

a) Power decays with the square of R. Doubling the distance: 25 W/m2
b) Without absorption wave can be reflected towards the observation point and the R-squared dependence is not true anymore.