		Name		Type
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List Number		e-mail		
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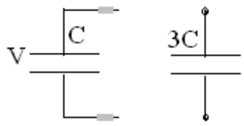
ATTENTION: Each question has only one correct answer and is worth one point. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account.

1. A point charge Q is located a short distance from a point charge $3Q$, and no other charges are present. If the electrical force on Q is $\vec{F}$, what is the electrical force on $3Q$?

(a) $-\vec{F}$ (b) $\vec{F}/3$ (c) $\vec{F}/\sqrt{3}$ (d) $3\vec{F}$ (e) $\sqrt{3}\vec{F}$

2. Consider a capacitor of capacitance C that is initially charged to a potential difference V. If this is then connected in parallel with a second initially uncharged capacitor of capacitance 3C, what is the final potential difference across its plates?

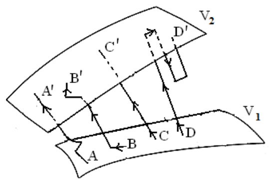


(a) V/8 (b) 4V (c) V/4 (d) 3V/4 (e) V/3

3. 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=R/2, y=0, z=0 (b) 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. (c) at the origin (d) at x=0, y=R/2, z=0 (e) at x=0, y=0, z=R/2

4. The figure shows two equipotential surfaces whose potentials are V_1 and V_2. The lines represent four paths (A → A′, B→ B′, C→C′, D → D′) along which equal test charges are moved. The work involved, can be said to be



(a) the greatest for path C → C′ (b) the greatest for path A → A′ (c) the greatest for path B → B′ (d) the same for all paths (e) the greatest for path D → D′

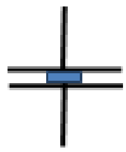
5. A free proton is placed midway between points A and B. The potential at point A is -20 V, and the potential at point B is +20 V. The potential at the midpoint is 0 V. The proton will

(a) move toward point B with constant velocity. (b) remain at rest. (c) move toward point A with constant velocity. (d) accelerate toward point A. (e) accelerate toward point B.

6. Which of the following angles between an electric dipole moment and an applied electric field will result in the most stable state?

(a) π rad (b) 0 rad (c) -π/2 rad (d) The electric dipole moment is not stable under any condition in an applied electric field. (e) π/2 rad

7. A dielectric with a dielectric constant $\chi = 4$ is inserted into a parallel plate capacitor, filling 1/3 of the volume, as shown in the figure. If the capacitance of the capacitor without the dielectric is C, what is the capacitance of the capacitor with the dielectric?



(a) 6C (b) 2C (c) C (d) 0.75C (e) 4C

8. The electric potential of a region of space is given by V= $7x^2y$ in SI units. Which of the following statements is false?

(a) The electric field has both x and y components apart origin. (b) The x-component of the electric field depends on both x and y. (c) The z-component of the electric field is zero everywhere in this region. (d) The magnitude of the electric field at the origin is zero. (e) The y-component of the electric field is proportional to y.

9. X and Y are two uncharged metal spheres on insulating stands, and are in contact with each other. A positively charged rod R is brought close to X as shown in Figure (a). Sphere Y is now moved away from X, as in Figure (b). What are the final charge states of X and Y?

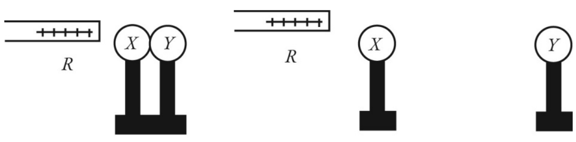


Figure (a) Figure (b)

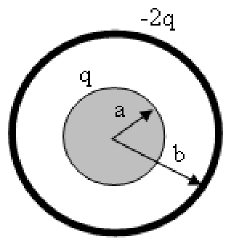
(a) X is positive and Y is neutral. (b) X is neutral and Y is positive. (c) X is negative and Y is positive. (d) Both X and Y are negative. (e) Both X and Y are neutral.

10. Consider a hollow spherical conductor with total charge $+5e$. The outer and inner radii are a and b, respectively. A charge of $-3e$ is placed at the center of the sphere. Which of the following statements is true?

(a) The charge on the outer surface of the sphere is $+5e$. (b) The charge on the inner surface of the sphere is $-3e$. (c) The total net charge of the sphere is $+8e$. (d) The total net charge of the sphere $+2e$. (e) The charge on the inner surface of the sphere is $+3e$.

Question 11-15

A very long conducting cylinder (length L) carrying a total charge +q, is surrounded by a conducting cylinder shell (also of length L) with total charge -2q as shown in the figure. (The coordinate r measures the distance from the axis of the cylinders and $\hat{\mathbf{r}}$ is the unit vector in the radial direction).



11. What is the electric field inside the conducting cylinder?

(a) $q\hat{\mathbf{r}}/\varepsilon_0$ (b) $q\hat{\mathbf{r}}/4\pi\varepsilon_0 a^2$ (c) $q\hat{\mathbf{r}}/2\pi\varepsilon_0 La$ (d) 0 (e) $-q\hat{\mathbf{r}}/4\pi\varepsilon_0 La^2$

12. What is the electric field in the region between the cylinders?

(a) $q\hat{\mathbf{r}}/(2\pi\varepsilon_0 Lr)$ (b) $3q\hat{\mathbf{r}}/(2\pi\varepsilon_0 Lr)$ (c) $-2q\hat{\mathbf{r}}/(2\pi\varepsilon_0 La)$ (d) $2kq\hat{\mathbf{r}}/(\varepsilon_0 aL)$ (e) $-q\hat{\mathbf{r}}/(2\varepsilon_0 Lr)$

13. What is the charge on the inner surface of the shell?

(a) +q (b) 0 (c) -q (d) -2q (e) -3q

14. What is the charge on the outer surface of the shell ?

(a) -2q (b) -3q (c) -q (d) +q (e) 2q

15. What is the electric field at points outside the conducting shell ?

(a) $-2q\hat{\mathbf{r}}/(2\pi\varepsilon_0 Lr)$ (b) $q\hat{\mathbf{r}}/(2\pi\varepsilon_0 Lr)$ (c) $q\hat{\mathbf{r}}/(4\pi\varepsilon_0 r)$ (d) $q\hat{\mathbf{r}}/(4\pi\varepsilon_0 r^2)$ (e) $-q\hat{\mathbf{r}}/(2\pi\varepsilon_0 Lr)$

Question 16-20

A parallel plate capacitor with air in the gap between the plates is connected to a 6.00 V battery. Each of the plates has an area of 50.0 cm^2. After charging, the energy stored in the capacitor is 78.0 nJ. Without disconnecting the capacitor from the battery, a dielectric is inserted into the gap and the energy of the capacitor increases by 312 nJ. (Take $k = \frac{1}{4\pi\varepsilon_0} = 9.00 \cdot 10^9$ N.m^2/C^2 and $\pi = 3$)

16. What is the dielectric constant of the dielectric?

(a) 4.00 (b) 1.25 (c) 5.00 (d) 3.00 (e) 2.50

17. What is the charge on the positive plate of the capacitor after the dielectric has been inserted?

(a) 26.0 nC (b) 32.5 nC (c) 130 nC (d) 78.0 nC (e) 65.0 nC

18. What is the charge on the positive plate of the capacitor before the dielectric has been inserted?

(a) 26 nC (b) 130 nC (c) 78.0 nC (d) 32.5 nC (e) 65.0 nC

19. What is the magnitude of the electric field between the plates before the dielectric is inserted?

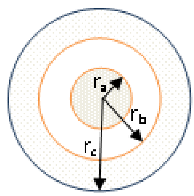
(a) $5.62 \cdot 10^5$ N/C (b) $2.81 \cdot 10^6$ N/C (c) $2.00 \cdot 10^5$ N/C (d) $1.40 \cdot 10^6$ N/C (e) $1.69 \cdot 10^6$ N/C

20. What is the magnitude of the electric field between the plates after the dielectric is inserted?

(a) $1.69 \cdot 10^6$ N/C (b) $1.40 \cdot 10^6$ N/C (c) $2.00 \cdot 10^5$ N/C (d) $5.62 \cdot 10^5$ N/C (e) $2.81 \cdot 10^6$ N/C

Question 21-23

A solid metal sphere with radius $r_a = 1$ cm is supported on an insulating stand at the center of a hollow, metal spherical shell with inner radius $r_b = 2$ cm and outer radius $r_c = 3$ cm. There is charge of q = +1 nC on the solid sphere and total charge of -3q on the spherical shell. (Take $k = 9 \cdot 10^9 \text{V} \cdot \text{m/C}$)



21. Calculate the potential V(r) in the region $r_b < r < r_c$,

(a) 0 V (b) -200 V (c) $\frac{9}{r}$ V (d) $-\frac{9}{r}$ V (e) -600 V

22. Calculate the potential V(r) in the region $0 < r < r_a$,

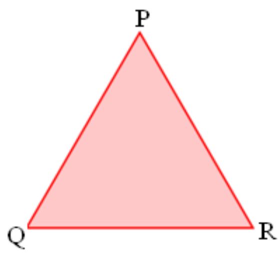
(a) -150 V (b) 0 V (c) 900 V (d) $-\frac{9}{r}$ V (e) $\frac{9}{r}$ V

23. What is the potential difference between the solid metal sphere and spherical metal shell $\Delta V = V(r_a) - V(r_b)$?

(a) 1100 V (b) 600 V (c) 200 V (d) 700 V (e) 450 V

Question 24-25

Three charges, q_1 =2 pC, q_2 = 3 pC, and q_3 = 4 pC, are located at the corners of an equilateral triangle with side length of L =1 m. (Take $k = 9 \cdot 10^9 \text{V} \cdot \text{m/C}$)



24. What is the work done to bring the third particle, q_3 to R from infinity?

(a) 15.0×10^{-14}J (b) 18.0×10^{-14}J (c) 5.4×10^{-14}J (d) 1.8×10^{-15}J (e) 11.4×10^{-14}J

25. What is the total potential energy stored in the final configuration of q_1, q_2, and q_3?

(a) 10.8×10^{-14}J (b) 1.8×10^{-14}J (c) 23.4×10^{-14}J (d) 12.6×10^{-14}J (e) 2.1×10^{-15}J

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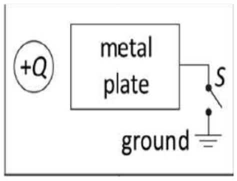
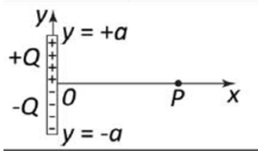
ATTENTION: Each question has only one correct answer and is worth one point. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account. The following identities are helpful: $\int_0^x \frac{y^2}{y-a}dy = \frac{x^2}{2} + ax + a^2\ln(1-\frac{x}{a})$, $\sin(x) \approx x$ **for small x**

1. A metal plate is connected by a conductor to the ground through a switch S. The switch is initially closed. A charge +Q is brought close to the plate without touching it, and then the switch is opened. After the switch is opened, the charge +Q is removed. What is the final charge on the plate?



(a) The plate is negatively charged (b) The plate is uncharged (c) Not enough information to decide (d) The plate could be either positively or negatively charged, depending on the charge it had before +Q was brought near (e) The plate is positively charged

2. A line of charge centered at point O and oriented along the y-axis has charge +Q distributed uniformly between y = 0 and y = +a and charge -Q distributed uniformly between y = 0 and y = -a (see figure). In this situation, the electric field at point P located on the x-axis as shown in the figure is directed:



(a) Along the positive x-axis (b) Along the negative x-axis (c) Along the positive y-axis (d) Along the negative y-axis (e) Electric field is zero

3. A cubical Gaussian box contains a negatively charged particle with charge -Q, and another positively charged particle with charge +Q lies outside the box. What can you say about the net electric flux through the box?

(a) The net electric flux is less than zero. (b) None of these, because flux is a vector. (c) The net electric flux is greater than zero. (d) The net electric flux is equal zero. (e) The net electric flux cannot be determined without more information.

4. There is a negative surface charge density in a certain region on the surface of a spherical solid conductor. Just beneath(under) the surface of this region, the electric field

(a) points inward, away from the surface of the conductor. (b) is zero. (c) points outward, toward the surface of the conductor. (d) not enough information given to decide. (e) points parallel to the surface.

5. Which of the following(s) is(are) **wrong** for a positive unit charge moving radially outward?

I) Potential difference near a positive charge located at the center is negative so electric force does positive work.
II) Potential difference near a positive charge located at the center is positive so electric force does negative work.
III) Potential difference near a negative charge located at the center is negative so electric force does positive work.
IV) Potential difference near a negative charge located at the center is positive so electric force does negative work.
V) Potential difference is zero means that electric force does no work.

(a) only I (b) II and III (c) I and IV (d) only V (e) only III

6. Which of the following(s) is/are true?

I) Equipotential surfaces for both positive and negative point charge form a sphere.
II) Equipotential surfaces for only positive point charge form a sphere.
III) Equipotential surfaces are planes for uniform electric field.
IV) On a given equipotential surface, the electric field E has the same value at every point..

(a) I and IV (b) only IV (c) I and III (d) II and III (e) only I

7. The capacitance of a spherical capacitor with inner radius a and outer radius b is proportional to:

(a) $\frac{ab}{b+a}$ (b) $\frac{a}{b}$ (c) $\frac{ab}{b-a}$ (d) $b^2 - a^2$ (e) b-a

8. The capacitance of a cylindrical capacitor can be increased by:

(a) decreasing the radius of the inner cylinder and increasing the radius of the outer cylindrical shell. (b) decreasing both the radius of the inner cylinder and the length. (c) increasing both the radius of the inner cylinder and the length. (d) only by decreasing the length. (e) increasing the radius of the outer cylindrical shell and decreasing the length.

9. Which term describes the rate at which electrical energy is used?

(a) Resistance (b) Voltage (c) Amper (d) Current (e) Power

10. What is the name for the flow of electrons in an electric circuit?

(a) Current (b) Inductance (c) Resistance (d) Capacitance (e) Voltage

Questions 11-15

A solid sphere has a volume charge density $\rho(r) = \frac{A}{r+c}$ where A and c are two constants, r is the radial distance from the center of the sphere.

11. What is the unit of A?

(a) $\frac{1}{m^2}$ (b) $\frac{C}{m^3}$ (c) $\frac{C^2}{m^3}$ (d) $\frac{C}{m^2}$ (e) $\frac{1}{m^3}$

12. If the total charge is Q, what is the magnitude of the electric field at $r > R$?

(a) $\frac{Q}{4\pi\epsilon_0(r+c)^2}$ (b) $\frac{Q}{4\pi\epsilon_0(r-c)^2}$ (c) $\frac{Q}{4\pi\epsilon_0 r^2}$ (d) $\frac{Q}{4\pi\epsilon_0 R^2}$ (e) $\frac{Qr}{4\pi\epsilon_0(r+c)^3}$

13. If the total charge is Q, what is the magnitude of the electric potential at $r > R$?

(a) $\frac{Qr}{4\pi\epsilon_0(r+c)^2}$ (b) $\frac{Q}{4\pi\epsilon_0(r+c)}$ (c) $\frac{Q}{4\pi\epsilon_0 r}$ (d) $\frac{Q}{4\pi\epsilon_0 R}$ (e) $\frac{Q}{4\pi\epsilon_0(r-c)}$

14. Express the total charge Q in terms of A,R,c.

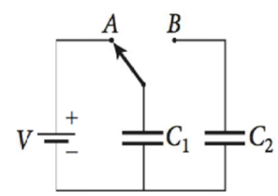
(a) $2\pi AR^2(1 + \frac{2c}{R} + \frac{2c^2}{R^2}\ln(1 - \frac{c}{R}))$
(b) $2\pi AR^2(1 - \frac{2c}{R} + \frac{2c^2}{R^2}\ln(1 + \frac{R}{c}))$ (c) $4\pi AR^2(1 + \frac{2c}{R} + \frac{2c^2}{R^2}\ln(1 - \frac{R}{2c}))$ (d) $4\pi AR^2(1 - \frac{2c}{R} + \frac{2c^2}{R^2}\ln(1 + \frac{c}{2R}))$
(e) $4\pi AR^2(1 + \frac{2c}{R} + \frac{2c^2}{R^2}\ln(1 + \frac{2R}{c}))$

15. Express the total charge at Q in the case where $c >> R$

(a) $\frac{4\pi}{3R}Ac^3$ (b) $\frac{4\pi}{3c}A(R+c)^3$ (c) $\frac{2\pi}{3R}cA^3$ (d) $\frac{2\pi}{3R}Ac^3$ (e) $\frac{4\pi}{3c}AR^3$

Questions 16-20

The figure shows a circuit with V=10 V, $C_1 = 2$ nF, and $C_2 = 3$ nF. The switch is closed, to A, and the capacitor C_1 is fully charged.



16. Find the energy delivered by the battery.

(a) 300 nJ (b) 100 nJ (c) 150 nJ (d) 200 nJ (e) 250 nJ

17. Find the energy stored in C_1.

(a) 200 nJ (b) 250 nJ (c) 150 nJ (d) 300 nJ (e) 100 nJ

18. Then the switch is thrown to B and the circuit is allowed to reach equilibrium. Find the total energy stored at C_1.

(a) 16 nJ (b) 30 nJ (c) 24 nJ (d) 12 nJ (e) 20 nJ

19. Find the total energy stored at C_2 after the switch is thrown to B and the circuit is allowed to reach equilibrium.

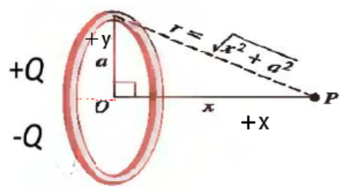
(a) 45 nJ (b) 30 nJ (c) 36 nJ (d) 18 nJ (e) 24 nJ

20. Find the total energy stored at $C_1 + C_2$ after the switch is thrown to B and the circuit is allowed to reach equilibrium.

(a) 40 nJ (b) 30 nJ (c) 60 nJ (d) 75 nJ (e) 50 nJ

Questions 21-23

A circular loop(ring), with a radius a is charged with +Q at the upper part and -Q at the lower part as shown in the figure.



21. What is the direction of the electric field at point P?

(a) y (b) $-x$ (c) $+z$ (d) x (e) $-y$

22. Calculate the potential V(r) at point P.

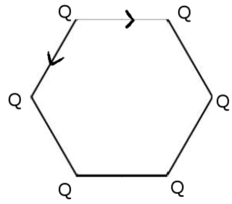
(a) $\frac{kQx}{(a^2+x^2)}$ (b) $\frac{2kQ}{(a^2+x^2)^{\frac{1}{2}}}$ (c) $\frac{2kQx}{(a^2+x^2)}$ (d) 0 (e) $\frac{2kQa}{(a^2+x^2)}$

23. Calculate the magnitude of the electric field at the middle of the ring.

(a) $\frac{2kQ}{\pi a^2}$ (b) 0 (c) $\frac{4kQ}{\pi a^2}$ (d) $\frac{kQ}{4\pi a^2}$ (e) $\frac{kQ}{2\pi a^2}$

Questions 24-25

Now take a positively charged regular hexagon wire with a side length of L. It is placed horizontally on a table. The positive charges at the corners repel each other and create a tension on the wire.



24. Express the tension T on the wire in terms of Q and length L.

(a) $\frac{kQ^2}{24L^2}(2\sqrt{3} + 5)$ (b) $\frac{kQ^2}{12L^2}(2\sqrt{3} + 5)$ (c) $\frac{kQ^2}{24L^2}(4\sqrt{3} + 15)$ (d) $\frac{kQ^2}{12L^2}(4\sqrt{3} + 15)$
(e) $\frac{kQ^2}{6L^2}(2\sqrt{3} + 5)$

25. Assume that the metal wire barely holds against the electric force. If one doubles the side lengths of the loop, what is the maximum **total** charge that one can have on the wire without breaking it?

(a) 4Q (b) 3Q (c) 6Q (d) Q/2 (e) 12Q

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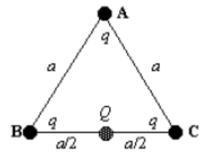
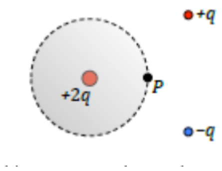
1. Three identical charges each with charge, q, are placed at the corners of an equilateral triangle. A fourth charge, Q, is placed midway between two of the charges as shown. Is it possible to choose a value for the charge Q such that the force on it due to the three corner charges is zero?
(a) No, because an additional charge would be needed to cancel the force on Q due to the charge at point A. (b) Yes, because it is centered between identical charges at points B and C. (c) No, because the forces on Q due to the charges at points B and C are in the same direction (d) No, because three force vectors can never add to zero. (e) None of them.

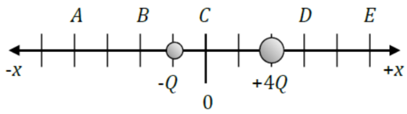


2. Suppose an electric field exists in a certain region of space. A test charge moves from point A to point B in the field. The work done by the field during this process is equal to
(a) the potential difference between points A and B. (b) the difference in the potential energy of the charge at point A and at point B. (c) none of them. (d) the difference between the value of the electric field at point A and at point B. (e) zero if the electric field is uniform.

3. Charges of +2q, +q, and -q are distributed in an area as shown in figure. Consider a Gaussian surface located around the +2q charge, with a point P located on the surface as shown. Which of the statements below is true?
(a) The electric field is the same everywhere inside the Gaussian surface. (b) The net electric field at point P can be determined using the Gaussian surface shown. (c) The net flux through the Gaussian surface depends only on the +2q charge. (d) The electric field at P depends only on the +2q charge. (e) The electric field is the same everywhere on the Gaussian surface.

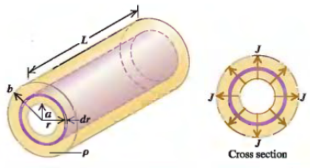


4. Two charges, of magnitude -Q and +4Q, are located as indicated in the diagram above. At which position will the electric field due to these two charges be zero?
(a) C (b) B (c) E (d) A (e) D



5. If the electron drift velocity is tripled in a wire, what effect does it do on the current density in this wire?
(a) it decreases by a factor of two (b) it increases by a factor three (c) it decreases by a factor of three (d) it increases by a factor of two (e) it stays the same

6. Figure shows the current flows radially from inside of the conductor toward outside (not along the length of the conductor) in a hollow cylinder with length L and inner and outer radii a and b. What is the resistance to this radial current flow if its resistivity is ρ.



(a) $R = (\rho\pi)\ln(b^2 - a^2)$ (b) $R = \frac{\rho}{2\pi L}\ln(b/a)$ (c) $R = \frac{\pi\rho}{L(b^2-a^2)}$ (d) $R = (\rho\pi)\frac{Lb^2}{(b^2-a^2)}$
(e) $R = (\rho\pi)(b^2 - a^2)$

7. The current in a wire varies with time according to the relationship $I = 55A - 2(A/s^2)t^2$. How many coulombs of charge pass a cross-section of the wire in the time interval between $t = 0$ and $t = 3s$?
(a) 52 A (b) 124 A (c) 147 A (d) 152 A (e) 48 A

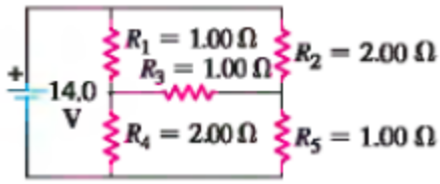
8. The electrostatic potential between the plates of a parallel plate capacitor ....
(a) increases with the position squared from the positive to the negative plate. (b) is constant. (c) increases linearly with position from the positive to the negative plate. (d) is equal to zero. (e) decreases linearly with position from the positive to the negative plate.

9. A spherical capacitor consists of a spherical conducting shell of radius b and charge -Q concentric with a smaller conducting sphere of radius a and charge +Q. Enter an expression for the capacitance of this device in terms of Coulomb's Constant k and the two radii a and b.
(a) $\frac{ab}{k(b-a)}$ (b) $\frac{4ab}{k(b+a)}$ (c) $\frac{4kab}{(b-a)}$ (d) $\frac{4kab}{(b+a)}$ (e) $\frac{4ab}{k(b-a)}$

10. Keeping the total charge on a capacitor fixed, what will happen to the electric energy density in a capacitor if one slides a dielectric material between two plates of the capacitor at hand?
(a) Decrease (b) Will not change (c) Density will become polarized (d) Information given above is not enough (e) Increase

Questions 11-15

In the circuit given below each resistor represent a light bulb. Let $R_1 = 1\ \Omega$, $R_2 = 2\ \Omega$, $R_3 = 1\ \Omega$, $R_4 = 2\ \Omega$ and $R_5 = 1\ \Omega$.



11. What is the current flowing through the battery?
(a) 16 A (b) 18 A (c) 22 A (d) 8 A (e) 10 A

12. What is the current flowing through R_1?
(a) 4 A (b) 8 A (c) 6 A (d) 10 A (e) 2 A

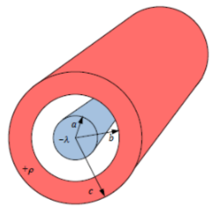
13. What is the current flowing through R_2?
(a) 10 A (b) 8 A (c) 4 A (d) 6 A (e) 2 A

14. What is the current flowing through R_3?
(a) 4 A (b) 10 A (c) 8 A (d) 6 A (e) 2 A

15. What is the equivalent resistor?
(a) $10\ \Omega$ (b) $1.4\ \Omega$ (c) $4.2\ \Omega$ (d) $6\ \Omega$ (e) $3.8\ \Omega$

Questions 16-20

An infinitely long cylindrical conductor has a radius a and a linear charge density of -λ as shown above. The conductor is surrounded by a cylindrical shell made of a nonconducting material of inner radius b, outer radius c, and with a constant volume charge density of $+\rho$. The conductor and nonconductor are located concentrically about a common axis.



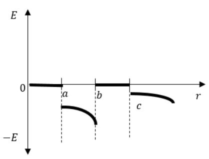
16. Determine the net electric flux per unit length passing through a cylindrically symmetric Gaussian surface located just outside the surface of the conductor.
(a) $\lambda\rho/\epsilon_0$ (b) λ/ϵ_0 (c) $-\rho/\epsilon_0$ (d) $-\lambda/\epsilon_0$ (e) ρ/ϵ_0

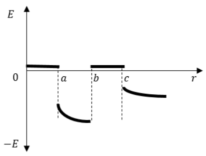
17. Use Gauss's Law to determine the magnitude of the electric field E as a function of radius r, where: $r < a$.
(a) $\frac{k\rho}{r}$ (b) $-\frac{k\rho}{r}$ (c) $-\frac{k\lambda}{\epsilon_0 r}$ (d) 0 (e) $-\frac{k\lambda}{r}$

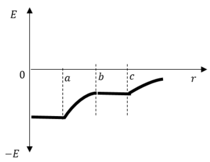
18. Use Gauss's Law to determine the magnitude of the electric field E as a function of radius r, where: $a < r < b$
(a) $-\frac{2k(\rho\pi(r^2-a^2)-\lambda)}{r}$ (b) $\frac{k\rho}{r}$ (c) $\frac{2k\lambda}{r}$ (d) $-\frac{2k(\rho\pi(b^2-a^2)-\lambda)}{r}$ (e) $\frac{k\lambda}{r}$

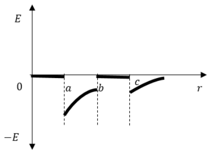
19. Use Gauss's Law to determine the magnitude of the electric field E as a function of radius r, where: $r > c$.
(a) $\frac{2k(\rho\Pi(c^2-b^2)-\lambda)}{r}$ (b) $\frac{2k\rho(r^2-c^2)}{r}$ (c) $\frac{-2k\lambda(r^2-c^2)}{r}$ (d) $\frac{k\rho}{r}$ (e) $\frac{-2k(\rho\Pi(r^2-c^2)-\lambda)}{r}$

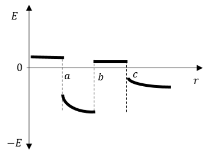
20. Putting an uncharged conducting cylinder around the linear charge density causes the uncharged cylinder to become polarized, with positive charges at the inner surface and negative charges at the outer surface. There is no electric field inside either conductor, and thus no change in electric potential inside the conductors.The following graphs require a general qualitative understanding of how electric field and electric potential changes work, without having to solve for specific functions. Which of the following could be the electric field versus r?

(a)


(b)


(c)


(d)


(e)


Questions 21-25

A total charge of Q is placed on a conducting sphere (sphere 1) of radius R_1.

21. What is the electric potential, V_1, at the surface of sphere 1 assuming that the potential infinitely far away from it is zero? (Hint: What is the change in potential if a charge is brought from infinitely far away, where $V(\infty) = 0$, to the surface of the sphere?)
(a) kQ/R_1 (b) 0 (c) kQ^2/R_1^2 (d) kQ/R_1^2 (e) kQ^2/R_1

22. A second conducting sphere (sphere 2) of radius R_2 with an initial net charge of zero ($q = 0$) is connected to sphere 1 using a long thin metal wire. How much charge flows from sphere 1 to sphere 2 to bring them into equilibrium?
(a) $(\frac{R_1}{R_1+R_2})Q$ (b) $(\frac{R_2^2}{(R_1+R_2)^2})Q$ (c) $(\frac{R_2}{R_1+R_2})Q$ (d) $(\frac{R_2}{R_1})Q$ (e) $(\frac{R_1}{R_2})Q$.

23. After the spheres are connected, what is the absolute value of the electric field on the surface of sphere 1?
(a) $\frac{kQ}{R_1^2}$ (b) $\frac{kQ}{R_2^2}$ (c) $\frac{kQ}{R_2(R_1+R_2)}$ (d) $\frac{kQ}{(R_1+R_2)^2}$ (e) $\frac{kQ}{R_1(R_1+R_2)}$

24. After the spheres are connected, what is the absolute value of the electric field on the surface of sphere 2?
(a) $\frac{kQ}{(R_1+R_2)^2}$ (b) $\frac{kQ}{R_2^2}$ (c) $\frac{kQ}{R_1^2}$ (d) $\frac{kQ}{R_1(R_1+R_2)}$ (e) $\frac{kQ}{R_2(R_1+R_2)}$

25. After the spheres are connected, what is the absolute value of the V_2, at the surface of sphere 2 assuming that the potential infinitely far away from it is zero?
(a) $\frac{kQ}{R_2}$ (b) $\frac{kQR_1}{(R_1+R_2)^2}$ (c) $\frac{kQ}{(R_1+R_2)}$ (d) $\frac{kQR_2^2}{(R_1+R_2)^2}$ (e) $\frac{kQ}{R_1}$

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Student ID		Signature		

ATTENTION: Each question has only one correct answer and is worth one point. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account.
Please take $e = 1.6 \times 10^{-19}$**C,** $k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \frac{N.m^2}{C^2}$

1. Two large, flat, horizontally oriented isolated plates carrying $+Q$ and $-Q$ charges, are parallel to each other, a distance d apart where d is small compared to the area of the plates. Half way between the two plates the electric field has magnitude E. If the separation of the plates is reduced to $d/2$ what is the magnitude of the electric field half way between the plates now?

(a) $4E$ (b) $E/2$ (c) $2E$ (d) E (e) 0

2. If 12.8×10^{-6}J of work is necessery to move 0.8 nC of charge from a positive plate to a negative plate, what is the potential difference (voltage) between the plates?

(a) 16 V (b) 0.16 V (c) 6.25 V (d) 16 kV (e) 6.25 kV

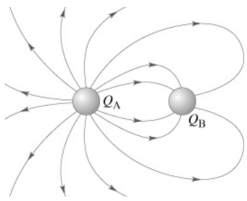
3. In electrostatics (assuming $V(x \to \infty) = 0$) which of the following statements is not correct?

(a) Potential inside a spherical shell carrying a net charge on it is zero. (b) Potential difference between any points in a conductor is zero. (c) Potential of a charge becomes zero only at infinite distance to the charge. (d) Potential is a scaler quantity. (e) Potential due to discrete charges can be calculated from the superposition of the potentials of the individual charges.

4. A positive charge q with mass m moves in the direction of electric field from point A to point B. What you can not say about it?

(a) Its kinetic energy increases. (b) Its potential energy increases. (c) The work necessary to move this charge is negative. (d) The work done on the charge is independent of the path. (e) The charge accelerates in the direction of the electric field.

5. In the figure, the electric field lines are shown for a system of two point charges Q_A, and Q_B. Which of the following could represent the magnitudes and signs of Q_A, and Q_B? (take q to be a positive quantity)



(a) $Q_A = -3q$, $Q_B = +7q$ (b) $Q_A = +7q$, $Q_B = -3q$ (c) $Q_A = +3q$, $Q_B = -7q$ (d) $Q_A = +q$, $Q_B = -q$ (e) $Q_A = -7q$, $Q_B = +3q$

6. Which of the following identifies the electromotive force (emf)?

I) Emf is the voltage developed by any source of electrical energy such as battery or dynamo.
II) Emf sources convert chemical, mechanical, and other forms of energy into electrical energy.
III) EMF is defined as the difference in electric potential between two points of a conducting wire when an electric current of one ampere dissipates one watt of power between those points.
IV) Emf is the electric potential energy per unit charge.

(a) I (b) All is true (c) III and IV (d) I, II (e) I, II and III

7. Which of the following experiments should be performed if you want to measure the exact or very approximate value of the electromotive force of a battery?

I) Measure the potential difference between the leads of the battery when the current of the circuit is zero.
II) Measure the potential difference between the leads of the battery when the net resistance which is series to the battery is large enough.
III) Measure the potential difference between the leads of the battery when the net resistance which is series to the battery is small enough.

(a) I and II (b) II and III (c) I (d) II (e) III

8. When the dielectric constant κ of the medium between the plates of a capacitor is increased, while the charges on the plates kept constant, which of the following is/are true?

I) Potential difference between the plates increases. II) Electric field between the plates decreases. III) Potential energy of the capacitor decreases.

(a) All is true (b) I and III (c) Only I (d) I and II (e) II and III

9. For which surfaces is Gauss's law valid?

(a) Only spherical closed surfaces. (b) All surfaces open or closed. (c) Only cylinderical open surfaces. (d) All open surfaces. (e) All closed surfaces.

Questions 10-13

A piece of metal has a cavity inside. A negative charge $-Q$ is placed inside the cavity. The metal is grounded.

10. What is the excess charge q induced on the inner surface of the cavity, if any?

(a) q =0 due being metal (b) q=+Q due to Gauss's law (c) $q = -Q$ due to being metal (d) $q = -Q$ due to charge conservation (e) $q = -Q$ due to the Gauss's law

11. Is there any charge on the surface of the metal ?

(a) $q = +Q$ due to charge conservation (b) $q = -Q$ due to charge conservation (c) q =0 due to being grounded (d) $q = -Q$ due to the Gauss's law (e) q =0 due to being metal

12. Is there an electric field inside the cavity?

(a) E =0 due to no Electric flux (b) $E \neq 0$ due to net Electric flux (c) E =0 because of the metal being grounded (d) E =0 due to induced charge on the inner surface of the metal (e) E =0 due to charge in the cavity and the charge on the inner surface of the metal

13. Would someone measure an electric field outside the metal?

(a) They can not because the $-Q$ charge is in the cavity not on the surface of the solid (b) They can because induced $-Q$ charge on the outer surface of the solid due to charge conservation (c) They can because induced $-Q$ charge on the outer surface of the solid (d) They can not because metals can shield charge in the cavity whether it is grounded or not (e) Can not due to being grounding

Questions 14-16

In a rectangular coordinate system a positive point charge $q = 6 \times 10^{-9}$C is placed at the point x =+0.1 m, y =0 m, and an identical point charge is placed at $x = -0.1$ m, y =0.

14. What is the magnitude of the electric field at the origin?

(a) 5400 V/m (b) 2800 V/m (c) 0 V/m (d) 1350 V/m (e) 10800 V/m

15. What is the magnitude of the electric potential at the origin?

(a) 270 V (b) 1080 V (c) 0 V (d) 10800 V (e) 540 V

16. What is the magnitude of the electric force that applies to a charge $q = 1$ nC located at x =0 m, y =0.1m?

(a) $5400\sqrt{2}$ nN (b) $3600/\sqrt{2}$ nN (c) $2700\sqrt{2}$ nN (d) $1350\sqrt{2}$ nN (e) $1350/\sqrt{2}$ nN

17. A non-uniform charged rod with a charge density $\lambda = x^2 a$ that lies on the positive x-axis between $x = d$ and $x = d + l$. If the total charge is Q, what is the constant a?

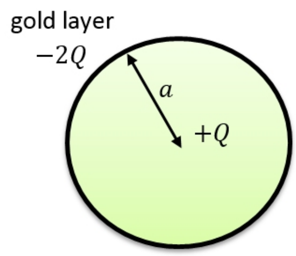
(a) $\frac{Q}{d^2l+dl^2-d^3/3}$ (b) $\frac{Q}{d^2l+dl^2+d^3/3}$ (c) $\frac{3Q}{l^3}$ (d) $\frac{3Q}{d^3}$ (e) $\frac{Q}{d^2l+dl^2+l^3/3}$

18. What is the magnitude and direction of the electric field at the origin due to a non-uniform charged rod with a charge density $\lambda = x^2 a$ that lies on the positive x-axis between $x = d$ and $x = d + l$?

(a) $-\frac{1}{4\pi\epsilon_0} al\ \hat{i}$ (b) $-\frac{1}{4\pi\epsilon_0}\frac{a}{\sqrt{l+d}}\ \hat{i}$ (c) $-\frac{1}{4\pi\epsilon_0}\frac{a}{dl^2+d^2l+l^3/3}\ \hat{i}$ (d) $\frac{1}{4\pi\epsilon_0}\frac{a}{dl^2+d^2l+l^3/3}\ \hat{i}$ (e) $\frac{1}{4\pi\epsilon_0}\frac{a}{\sqrt{1+d}}\ \hat{i}$

Questions 19-22

A solid non-conducting sphere of radius a has a total charge Q uniformly distributed throughout its volume. The surface of the sphere is coated with a thin conducting layer of gold. A total charge of $-2Q$ is placed on this conducting layer. Take $Q = 10$ nC and $a = 1.0$ m. r is the distance measured from the center. (Take π=3)



19. What is the electric field E inside the sphere and at $r = 1/3$ m?

(a) 3 V/m (b) 0 V/m (c) 10 V/m (d) 30 V/m (e) 300 V/m

20. What is the electric field E at $r = 1$ m <u>inside</u> the gold layer?

(a) 30 V/m (b) 0 V/m (c) 10 V/m (d) 9 V/m (e) 300 V/m

21. What is the electric field E outside and at $r = 3$ m?

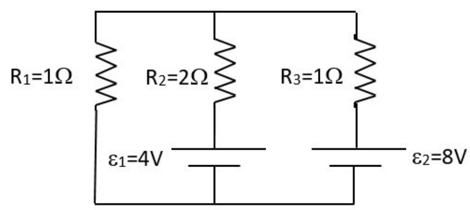
(a) -20 V/m (b) 1 V/m (c) 20 V/m (d) -10 V/m (e) 10 V/m

22. What is the charge density at the inner surface of the gold layer?

(a) $-5/3$ nC/m^2 (b) $5/3$ nC/m^2 (c) 0 nC/m^2 (d) $-5/6$ nC/m^2 (e) $5/6$ nC/m^2

Questions 23-25

In the circuit shown in the Figure:



23. What is the magnitude of the electric current that flows through the R_1?

(a) 4 A (b) 12 A (c) 6 A (d) 3 A (e) 1 A

24. What is the potential difference between the terminals of R_2?

(a) 2 V (b) 0 V (c) 3 V (d) 8 V (e) 7 V

25. What is the dissipated energy on R_3 during 10 seconds?

(a) 120 J (b) 107 J (c) 214 J (d) 160 J (e) 80 J

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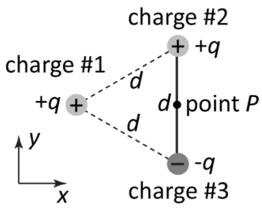
ATTENTION: Each question has only one correct answer and is worth one point. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account.
Please take $e = 1.6\times10^{-19}$**C,** $k = \frac{1}{4\pi\epsilon_0} = 9\times10^9\,\frac{N.m^2}{C^2}$

1. When you rub a plastic rod with fur, the plastic rod becomes negatively charged and the fur becomes positively charged. As a consequence of rubbing the rod with the fur:
(a) The rod gains mass and the fur loses mass. (b) The rod loses mass and the fur gains mass. (c) None of the other options is correct. (d) The rod and fur both gain mass. (e) The rod and fur both lose mass.

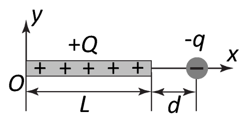
Questions 2-3

Three point charges located in vacuum lie at the vertices of an equilateral triangle with side length d as shown in the figure.

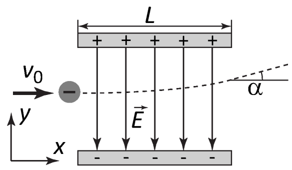


2. The net electric force exerted on the charge #1 is:
(a) $\frac{1}{4\pi\epsilon_0}\, q^2/(2d^2)\hat{j}$ (b) 0 (c) $\frac{1}{4\pi\epsilon_0}\, 2q^2/d^2\hat{j}$ (d) $\frac{1}{4\pi\epsilon_0}\,(\sqrt{3}q^2)/(2d^2)\hat{j}$ (e) $-\frac{1}{4\pi\epsilon_0}\, q^2/d^2\hat{j}$

3. The net electric field created by all three charges at (point P) is:
(a) $\frac{1}{4\pi\epsilon_0}\,(4q/3d^2)\hat{i}$ (b) $\frac{1}{4\pi\epsilon_0}\,(q/d^2)\left(\frac{1}{3}\hat{i}+2\hat{j}\right)$ (c) $\frac{1}{4\pi\epsilon_0}\,(q/d^2)\left(\frac{1}{3}\hat{i}-2\hat{j}\right)$ (d) $\frac{1}{4\pi\epsilon_0}\,(4q/d^2)\left(\frac{1}{3}\hat{i}+2\hat{j}\right)$
(e) $\frac{1}{4\pi\epsilon_0}\,(4q/d^2)\left(\frac{1}{3}\hat{i}-2\hat{j}\right)$



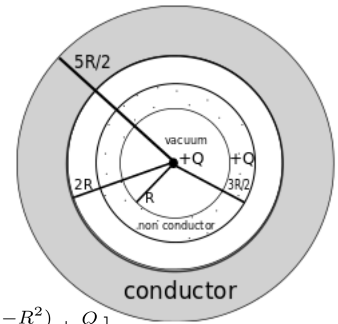
4. Positive charge $+Q$ is distributed uniformly along the x-axis from $x = 0$ to $x = L$. A negative point charge $-q$ is located on the positive x-axis at a distance d to the right of the end of charge distribution $+Q$ (see picture). What is the electric force acting on the negative charge $-q$?
(a) $-\frac{1}{4\pi\epsilon_0}\frac{Qq}{(L+d)^2}\hat{i}$ (b) $-\frac{1}{4\pi\epsilon_0}\frac{Qq}{(L+d)}\hat{i}$ (c) $-\frac{1}{4\pi\epsilon_0}\frac{Qq}{d(L+d)}\hat{i}$ (d) $-\frac{1}{4\pi\epsilon_0}\frac{Qq}{(\frac{L}{2}+d)^2}\hat{i}$ (e) $-\frac{1}{4\pi\epsilon_0}\frac{Qq}{d^2}\hat{i}$



5. An electron with velocity $v_0 = 8000$ m/s directed along the positive x-axis enters the gap between two metal plates with a uniform, vertically oriented electric field $\vec{E}$ between them (see the picture). The length of the plates is $L = 32$ mm. What is the electric field strength between the plates if the electron is deflected vertically by angle $\alpha = 1.6\times10^{-3}$ rad? Take electron mass $m_e = 10^{-30}$ kg, electron charge $q_e = 1.6\times10^{-19}$ C, $\tan\alpha \approx \alpha$, and ignore the effect of gravity on the electron.
(a) 8×10^{-4} N/C (b) 4×10^{-3} N/C (c) 2×10^{-5} N/C (d) 8×10^{-5} N/C (e) 2×10^{-4} N/C

Questions 6-9

Charges are distributed in spherical geometries as shown in the picture. Q charge is placed at the center of a sphere. Between R and 3R/2 there is a nonconducting material and Q charge is uniformly distributed in it. Between 2R and 5R/2 there is conducting shell with no charge.



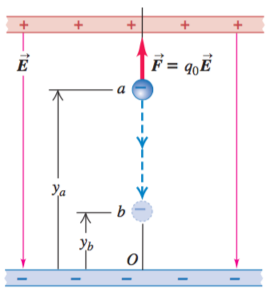
6. What is the E field between 0 and R ?
(a) $-\frac{Q}{4\pi\varepsilon_0 r}$ (b) $\frac{Q}{4\pi\varepsilon_0 r^2}$ (c) 0 (d) $\frac{Qr}{4\pi\varepsilon_0}$ (e) $\frac{Q}{4\pi\varepsilon_0 r^3}$

7. What is the electric field between R and 3R/2 ?
(a) 0 (b) $\frac{1}{4\pi r^3}\left[\frac{4Q(r^3-R^3)}{5R^3\varepsilon_0}-\frac{Q}{\varepsilon_0}\right]$ (c) $\frac{1}{4\pi r^2}\left[\frac{4Q(r^3-R^3)}{5R^2\varepsilon_0}\right]$ (d) $\frac{1}{4\pi r^2}\left[\frac{8Q(r^3-R^3)}{19R^3\varepsilon_0}+\frac{Q}{\varepsilon_0}\right]$ (e) $\frac{1}{2\pi r^2}\left[\frac{4Q(r^2-R^2)}{5R^3\varepsilon_0}+\frac{Q}{\varepsilon_0}\right]$

8. What is the electric field between 2R and 5R/2 ?
(a) 0 (b) $\frac{Q}{4\pi\varepsilon_0 r^2}$ (c) $\frac{-Q}{2\pi\varepsilon_0 r^2}$ (d) $\frac{2Q}{4\pi\varepsilon_0 r^3}$ (e) $\frac{3Q}{2\pi\varepsilon_0 r^2}$

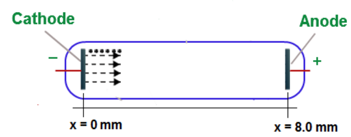
9. What is the electric field at r>5R/2 ?
(a) $\frac{2Q}{4\pi\varepsilon_0 r^2}$ (b) $\frac{Q}{4\pi\varepsilon_0 r^3}$ (c) 0 (d) $\frac{2Q}{4\pi\varepsilon_0 r^3}$ (e) $\frac{Q}{4\pi\varepsilon_0 r^2}$

10. According to the figure, which is the following true for a negative test charge moving in the direction of the electric field E?
(a) Field does negative work on charge, potential energy is not changed (b) Field does positive work on charge, potential energy increases (c) Field does positive work on charge, potential energy decreases (d) Field does negative work on charge, potential energy increases (e) Field does negative work on charge, potential energy decreases



Questions 11-14

A vacuum tube diode consists of concentric cylindrical electrodes, the negative cathode and the positive anode. Because of the accumulation of charge near the cathode the electric potential between the electrodes can be given by V(x)=C $x^{4/3}$, where x is the distance from the cathode and C is a constant, characteristic of a particular diode and operating conditions. Assume that the distance between the cathode and anode is 8.0 mm and the potential difference between electrodes is 240 V:



11. Determine the value of C.

(a) 3.0×10^4 V/m$^{4/3}$ (b) 30.0×10^4 V/m$^{4/3}$ (c) 8.0×10^4 V/m$^{4/3}$ (d) 1.5×10^4 V/m$^{4/3}$ (e) 15.0×10^4 V/m$^{4/3}$

12. Obtain the electric field between the electrodes as a function of x.

(a) $(-8.0\times10^5)x^{1/3}$ (b) $(-2.0\times10^5)x^{1/3}$ (c) $(1.0\times10^5)x^{1/3}$ (d) $(8.0\times10^5)x^{1/3}$ (e) $(2.0\times10^5)x^{1/3}$

13. E points:

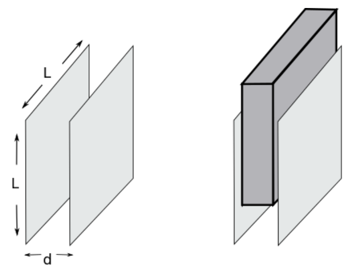
(a) out of the page (b) from the negative cathode to the positive anode (c) from the positive anode to the negative cathode (d) parallel to the plates from left to right (e) into the page

14. Determine the force on an electron on the anode plate(x = 8 mm).(e = 1.6×10^{-19} C)

(a) 6.4×10^{-15} N (b) 1.6×10^{-15} N (c) -6.4×10^{-15} N (d) 3.2×10^{-15} N (e) -3.2×10^{-15} N

Questions 15-20

A parallel plate capacitor has square plates of side L=10 cm separated by a distance d=3 mm as shown in the figure. the capacitor is changed by a battery with potential difference $V_0 = 100$ V; the battery is then connected.



15. Determine the capacitance of C_0.

(a) 100 pF (b) 0.3 pF (c) 10 pF (d) 30 pF (e) 300 pF

16. Determine the charge of the capacitor.

(a) 1 nC (b) 3nC (c) 100 nC (d) 30 nC (e) 300 nC

17. Determine the electric potential energy stored in the capacitor at this point.

(a) 100 nJ (b) 150 nJ (c) 15 nJ (d) 5 nJ (e) 50 nJ

18. Now a slab of plexiglass ($\kappa = 3$) is then inserted so that it fills 2/3 of its volume between the plates as shown in the figure. What is the new capacitance?

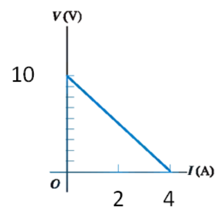
(a) 25 pF (b) 10 pF (c) 5 pF (d) 50 pF (e) 100 pF

19. What is the new potential difference between the plates in case c?

(a) 600 V (b) 6 V (c) 60 V (d) 30 V (e) 10 V

20. What is the charge in the new capacitor?

(a) 10 nC (b) 30 nC (c) 3 nC (d) 6 nC (e) 60 nC



21. An idealized voltmeter is connected across the terminals of a battery while the current is varied. Figure shows a graph of the voltmeter reading V as a function of the current I through the battery. Find the emf ϵ and the internal resistance of the battery.

(a) 12 V, 3 Ω (b) 8 V, 2 Ω (c) 10 V, 0.25 Ω (d) 10 V, 0.5 Ω (e) 10 V, 2.5 Ω

Questions 22-24

An electrical conductor designed to carry large currents has a circular cross section 4 mm in diameter and is 12.0 m long. The resistance between its ends is 0.100 Ω. (e = 1.6×10^{-19} C, π=3)

22. What is the resistivity of the material?

(a) $3\cdot10^{-7}$ Ωm (b) $2.5\cdot10^{-8}$ Ωm (c) $5\cdot10^{-8}$ Ωm (d) $2\cdot10^{-7}$ Ωm (e) 10^{-7} Ωm

23. If the electric-field magnitude in the conductor is 1.6 V/m. What is the total current?

(a) 75 A (b) 388 A (c) 192 A (d) 19.2 A (e) 38.8 A

24. If the material has 10^{29} free electrons per cubic meter, find the average drift of the charge carriers.

(a) $3\cdot10^{-3}$ m/s (b) $2\cdot10^{-3}$ m/s (c) 10^{-3} m/s (d) $4\cdot10^{-3}$ m/s (e) $1.6\cdot10^{-3}$ m/s

25. A toaster using a Nichrome heating element operates at 220 V. When it is switched on at 20°C the heating element carries an initial current of 2.20 A. A few seconds later current reaches the steady value of 2.00 A. What is the final temperature of the element? The average value of the temperature coefficient of resistivity for Nichrome over the temperature range is $4\cdot10^{-4}$ $(C°)^{-1}$.

(a) 270°C (b) 250°C (c) 400°C (d) 500°C (e) 200°C

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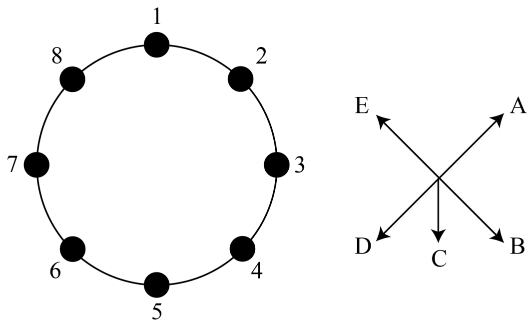
ATTENTION: Each question has only one correct answer and is worth one point. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account.

For calculations take: Speed of light $c = 3 \times 10^8$ m/s, $\pi = 3$, $k_e = 9 \times 10^9$ N.m^2/C^2

1. Eight particles of equal charge are located around a circle as shown in the figure. Which vector shown best represents the force experienced by charge 4?

(a) E (b) B (c) A (d) C (e) D

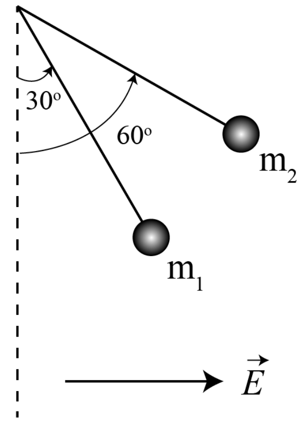


2. Two small identical spheres are separated by a distance d. The spheres originally have equal charges and the magnitude of the repulsive force that each experiences is F. If half of the charge on one sphere is moved to the other sphere, the magnitude of the force becomes

(a) F (b) 3F/4 (c) 3F (d) 3F/2 (e) F/2

3. A ball of mass m_1 and charge q is suspended from a light string in the presence of a horizontal electric field, $\vec{E}$, near the surface of the earth. At equilibrium it makes an angle of 30° with the vertical. When it is replaced by a mass of m_2 and charge q, it makes and angle of 60° with the vertical in equilibrium as shown below.What is the ratio of the masses m_1/m_2?

(a) $2/\sqrt{3}$
(b) $\sqrt{3}$
(c) 3
(d) $1/\sqrt{3}$
(e) 1/3



4. The electrostatic potential between the plates of a parallel plate capacitor ...

(a) ... increases quadratically with the position from the positive to the negative plate. (b) ... is constant. (c) ... is equal to zero. (d) ... increases linearly with position from the positive to the negative plate. (e) ... decreases linearly with position from the positive to the negative plate.

5. The magnitude of the electric field between the plates of a parallel plate capacitor ...

(a) ... is equal to zero. (b) ... is constant. (c) ... decreases linearly with position from the positive to the negative plate. (d) ... increases quadratically with the position from the positive to the negative plate. (e) ... increases linearly with position from the positive to the negative plate.

6. Two charged conducting spheres with charges $+Q$ and $-Q$ are separated by center to center distance d. The attractive force between them

(a) is greater than $k\,Q^2/d^2$ (b) is equal to $k\,Q^2/d^2$ (c) is zero. (d) is less than $k\,Q^2/d^2$ (e) is not well defined.

7. First charge a capacitor with a battery and then remove the capacitor from the battery so that the plates remain charged. You then insert a dielectric material with $K > 1$ centered between the plates (but it is not touching the plates). Which of the following increases in magnitude?

(a) The potential difference between the plates. (b) The electric energy stored between the plates. (c) The capacitance. (d) The magnitude of the electric field between the plates. (e) The charge on each plate.

8. The units of electric constant k is equivalent to

(a) $\text{Watt} \cdot \text{m} \cdot \text{s}^2/\text{C}^2$. (b) $\text{Watt} \cdot \text{s}^2/\text{C}^2 \cdot \text{m}^2$. (c) $\text{Watt} \cdot \text{m} \cdot \text{s}/\text{C}^2$. (d) $\text{Watt} \cdot \text{m}^2 \cdot \text{s}/\text{C}^2$. (e) $\text{Watt} \cdot \text{s}/\text{C}^2 \cdot \text{m}$.

9. A wire has a uniform cross sectional area of 1 cm^2 and a length of 1 m. When the potential difference across the wire is increased by $16\,V$, the current increases by 2 A. What is the resistivity of the wire?

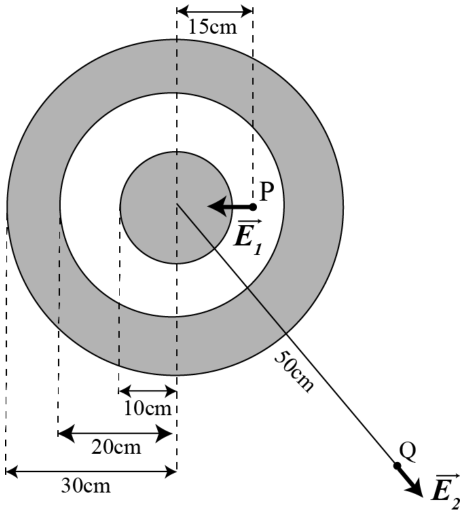
(a) $2 \cdot 10^{-4}\,\Omega \cdot m$ (b) $16 \cdot 10^{-4}\,\Omega \cdot m$ (c) $4 \cdot 10^{-4}\,\Omega \cdot m$ (d) $1 \cdot 10^{-4}\,\Omega \cdot m$ (e) $8 \cdot 10^{-4}\,\Omega \cdot m$

10. A potential difference of 16 V is maintained across an electrical device with a resistance of $4\,\Omega$. What total charge passes through a cross section of wire attached to this device over a period of 2 s?

(a) $8\,C$ (b) $0.5\,C$ (c) $4\,C$ (d) $2\,C$ (e) $32\,C$

Questions 11-15

A solid metal sphere of radius 10 cm is concentric with a hollow metal sphere with inner and outer radii of 20 cm and 30 cm, respectively (see the figure). The electric field at point P, at a distance of 15 cm from the center, is found to be $E_1 = 9 \cdot 10^5$ N/C, directed radially inward. The electric field at point Q, at a distance of 50 cm from the center, is found to be $E_2 = 18 \cdot 10^4$ N/C, directed radially outward.



11. What is the total charge on the surface of the solid sphere? (Use the constants given at the front page)

(a) $-1.5 \cdot 10^{-6}$ C (b) $-5 \cdot 10^{-6}$ C (c) $-4.5 \cdot 10^{-6}$ C (d) $-9 \cdot 10^{-6}$ C (e) $-2.25 \cdot 10^{-6}$ C

12. What is the total charge on the surface of the inner surface of the hollow sphere?

(a) $1.5 \cdot 10^{-6} C$ (b) $9 \cdot 10^{-6} C$ (c) $5 \cdot 10^{-6} C$ (d) $4.5 \cdot 10^{-6} C$ (e) $2.25 \cdot 10^{-6} C$

13. What is the total charge on the surface of the outer surface of the hollow sphere?

(a) $5 \cdot 10^{-6} C$ (b) $1.5 \cdot 10^{-6} C$ (c) $2.25 \cdot 10^{-6} C$ (d) $9 \cdot 10^{-6} C$ (e) $4.5 \cdot 10^{-6} C$

14. What is the magnitude of the electric field at a distance of 25 cm from the center?

(a) $13.5 \cdot 10^4 N/C$ (b) $24 \cdot 10^4 N/C$ (c) $15 \cdot 10^4 N/C$ (d) 0 (e) $5.4 \cdot 10^4 N/C$

15. What is the magnitude of the electric field at a distance of 4 cm from the center?

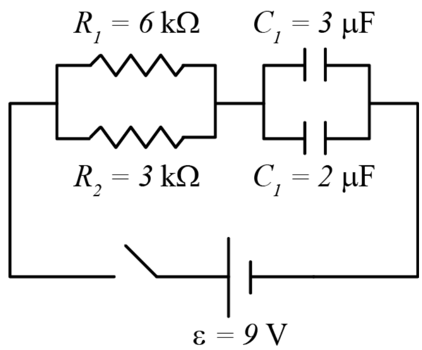
(a) $45 \cdot 10^4$ N/C (b) $24 \cdot 10^4$ N/C (c) $18 \cdot 10^4$ N/C (d) $9 \cdot 10^4$ N/C (e) 0

Questions 16-20

Consider the circuit shown in the figure. For calculations use the approximations: $e \approx 2.7$, $\sqrt{e} \approx 1.6$, $1/\sqrt{e} \approx 0.6$

16. Calculate the current flows from the circuit immediately after the switch is closed.

(a) 18 mA (b) 0.1 mA (c) 4.5 mA (d) 0 (e) 1 mA



17. Calculate the current flows from the circuit long after the switch is closed.

(a) 3 mA (b) 0.1 mA (c) 4.5 mA (d) 0 (e) 1 mA

18. Calculate the charge across the capacitor C_1 long after the switch is closed.

(a) 45 μ C (b) 27 μ C (c) 9 μ C (d) 18 μ C (e) 0

19. Calculate the charge across the capacitor C_2 long after the switch is closed.

(a) 0 (b) 9 μ C (c) 18 μ C (d) 45 μ C (e) 27 μ C

20. Calculate the charge across the capacitor C_2 after the switch is closed for 5 μ s.

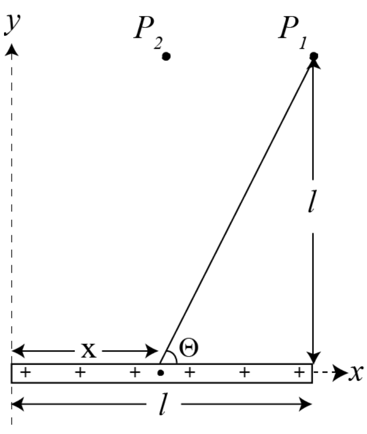
(a) 7.2 μ C (b) 14.4 μ C (c) 3.6 μ C (d) 28.8 μ C (e) 1.8 μ C

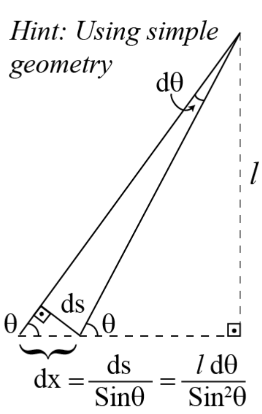
Questions 21-25

For questions 21-23, consider a positively homogeneously charged metal rod which is shown in the figure.

21. From point P_1 to point P_2 the electric potential difference $V_{P_1} - V_{P_2}$ ...

(a) ... can't be determined. (b) ... is positive. (c) ... is zero. (d) ... is negative. (e) ... is infinite.





22. The work done by us, in moving a positive charge with a slow constant velocity from point P_1 to point P_2, ...

(a) ... is zero.
(b) ... is infinite. (c) ... can't be determined. (d) ... is negative.
(e) ... is positive.

23. The work done by the electric field, when a positive charge is moved by us with a slow constant velocity from point P_1 to point P_2, ...

(a) ... is infinite. (b) ... can't be determined. (c) ... is negative.
(d) ... is zero.
(e) ... is positive.

24. Now consider the case when the metal rod's charge density is a function of the angle Θ with horizontal x axis as $\lambda = \lambda_0 \sin^2 \Theta$.

Express the total charge Q in terms of λ_0 and the length of the rod l.

(a) $\lambda_0 l\pi/2$ (b) $\lambda_0 l\pi/4$ (c) $\lambda_0 l\, 3\pi/2$ (d) $\lambda_0 l\pi/8$ (e) $\lambda_0 l\pi$

25. Express the electric potential V_{P_1} at point P_1, in terms of λ_0 and the electric constant k.

(a) $\frac{\sqrt{2}}{2} k\lambda_0$ (b) $(\sqrt{2}-1)k\lambda_0 l$ (c) $(\sqrt{2}-1)k\lambda_0/l$ (d) $k\lambda_0(1-\frac{\sqrt{2}}{2})$ (e) $\frac{\sqrt{2}}{2} k\lambda_0/l$

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For all questions take: Speed of light $c = 3 \times 10^8$ m/s, $\pi = 3$, $\epsilon_0 = 9 \times 10^{-12}$ C^2/N.m^2, electron charge $q_e = 1.6\ 10^{-19}$ C.

1. A spherical conducting shell with net charge $+q$ surrounds a point charge of $-q$ positioned at the centre of the shell. What are the charges on the inner and outer surfaces of the shell, respectively, when static equilibrium is reached?

(a) q, $2q$ (b) $2q$, q (c) $2q$, $3q$ (d) q, 0 (e) q, q

2. A solid sphere has a uniform charge density and a net charge of +6 nC. At electrostatic equilibrium the electric field inside the sphere

(a) varies as $1/r$ (b) is zero (c) varies as r (d) is constant. (e) varies as $1/r^2$

3. The electric field in a region of space is given as $E = -30x + 2$, where x is in meters and E is in Volts/meter. What is the electric potential at $x = 2$ meters, relative to the origin?

(a) -60 V (b) $+60$ V (c) 3 V (d) -3 V (e) $+56$ V

4. How does the energy stored in a parallel plate capacitor change when the separation between the plates is doubled while kept at the same potential?

(a) Cubed (b) Doubled (c) Halved (d) Remains the same (e) Cube rooted

5. Two uniformly charged infinitely long parallel wires with linear charge density λ are seperated with a distance r. The electrostatic force between the wires

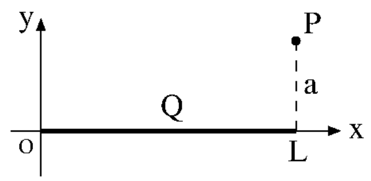
(a) varies as $1/r$ (b) varies as $1/r^2$ (c) is independent of the distance (d) varies as $1/r^3$ (e) varies as r

6. Electric flux through a closed surface is **always**

(a) zero, if there is a charge distribution in it.
(b) related to the shape of the surface.
(c) negative if net charge inside the surface is positive.
(d) positive if net charge inside the surface is negative.
(e) zero, if net charge inside the surface is zero.

Questions 7-9

A uniform line of charge of length L lying between $x = 0$ to $x = L$ is charged with Q.



7. Which of the following gives the x component of the electric field at point P?

(a) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{(L-x)\,\mathrm{d}x}{[(L-x)^2+a^2]^{3/2}}$ (b) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{\mathrm{d}x}{[(L-x)^2+a^2]}$ (c) $\frac{Q/L}{4\pi\epsilon_0}\int_0^a \frac{(L-x)\,\mathrm{d}x}{[(L-x)^2+a^2]^{3/2}}$ (d) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{x\,\mathrm{d}x}{[(L-x)^2+a^2]^{3/2}}$ (e) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{a\,\mathrm{d}x}{[(L-x)^2+a^2]^{3/2}}$

8. Which of the following is the y component of electric field vector at point P?

(a) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{\mathrm{d}x}{[(L-x)^2+a^2]}$ (b) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{(L-x)\,\mathrm{d}x}{[(L-x)^2+a^2]^{3/2}}$ (c) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{x\,\mathrm{d}x}{[(L-x)^2+a^2]^{3/2}}$ (d) $\frac{Q/L}{4\pi\epsilon_0}\int_0^a \frac{(L-x)\,\mathrm{d}x}{[(L-x)^2+a^2]^{3/2}}$ (e) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{a\,\mathrm{d}x}{[(L-x)^2+a^2]^{3/2}}$

9. Which of the following gives the electric potential at point P?

(a) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{(L-x)\mathrm{d}x}{[(L-x)^2+a^2]^{3/2}}$ (b) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{a\mathrm{d}x}{[(L-x)^2+a^2]^{3/2}}$ (c) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{\mathrm{d}x}{[(L-x)^2+a^2]^{1/2}}$ (d) $\frac{Q/L}{4\pi\epsilon_0}\int_0^a \frac{\mathrm{d}x}{[(L-x)^2+a^2]^{1/2}}$ (e) $\frac{Q/L}{4\pi\epsilon_0}\int_0^L \frac{\mathrm{d}x}{[x^2+a^2]^{1/2}}$

Questions 10-14

A spherical object with radius a has total charge $-Q$ distributed uniformly over its volume. r is the radial distance from the origin.

10. What is the magnitude and direction of the electric field in the region $r < a$?

(a) $-3Qr/4\pi\epsilon_0 a^3$ (b) $-Q/4\pi\epsilon_0 r^2$ (c) 0 (d) $-Q/2\pi\epsilon_0 ar$ (e) $-Qr/4\pi\epsilon_0 a^3$

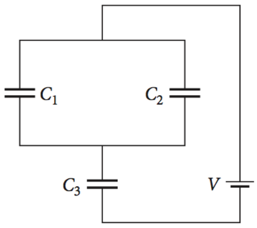
11. What is the electric potential at a distance $r > a$, assuming the potential is zero at infinity?
(a) $-Q/4\pi\epsilon_0 r$ (b) $-Q/4\pi\epsilon_0 a$ (c) $Qa/4\pi\epsilon_0 r^2$ (d) $-Qa^2/8\pi\epsilon_0 r^3$ (e) $-Qr/4\pi\epsilon_0 a^2$

12. What is the electric potential at a distance $r < a$?
(a) $-Q(3 - r^2/a^2)/8\pi\epsilon_0 a$
(b) $-Q(3 - a^2/r^2)/8\pi\epsilon_0 a$
(c) $-Q(2 - a^2/r^2)/4\pi\epsilon_0 a$
(d) $-Q(2 - r^2/a^2)/4\pi\epsilon_0 a$
(e) $-Q(2 - r/a)/4\pi\epsilon_0 a$

13. What is total energy stored in the electric field *outside* the sphere?
(a) $-Q^2/8\pi\epsilon_0 a$ (b) $Q^2/4\pi\epsilon_0 a$ (c) $Q^2/8\pi\epsilon_0 a$ (d) $3Q^2/8\pi\epsilon_0 a$ (e) $3Q^2/5\pi\epsilon_0 a$

14. What is the total energy stored in the electric field *inside* the sphere?
(a) $Q^2/20\pi\epsilon_0 a$ (b) $Q^2/40\pi\epsilon_0 a$ (c) $3Q^2/40\pi\epsilon_0 a$ (d) $-Q^2/40\pi\epsilon_0 a$ (e) $3Q^2/5\pi\epsilon_0 a$

Questions 15-18



Three capacitors with capacitances $C_1 = 2.0\ \mu$F, $C_2 = 4.0\ \mu$F, and $C_3 = 6.0\ \mu$F are connected in a circuit as shown in the figure, with an applied potential of V. After the charges on the capacitors have reached their equilibrium, the charge Q_2 on the second capacitor (C_2) is found to be 30 μC.

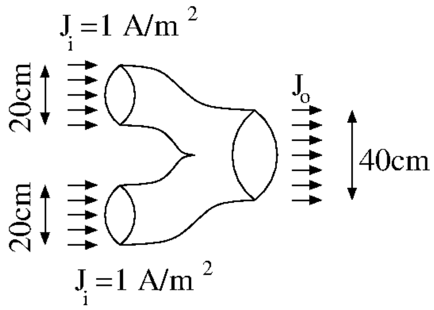
15. What is the charge, Q_1, on the capacitor C_1?
(a) 5 μC (b) 25 μC (c) 10 μC (d) 15 μC (e) 20 μC

16. What is the charge, Q_3, on capacitor C_3 ?
(a) 45 μC (b) 30 μC (c) 35 μC (d) 15 μC (e) 25 μC

17. What is the magnitude of the applied voltage (V) ?
(a) 25 (b) 15 (c) 10 (d) 5 (e) 20

18. How much energy is stored in C_1 ?
(a) 0 μJ (b) 125/4 μJ (c) 225/4 μJ (d) 12.5/4 μJ (e) 22.5/4 μJ

Questions 19-22



A conductor made from a copper-alloy is given in the figure. Assume all branches have circular cross sections. The diameter of both of the inputs is 20 cm and the diameter of the output is 40 cm. The current densities (J) at both of the inputs are equal and given as 1A/m^2 each. (Charge density of free electrons $n_e = 5.0\ 10^{28}(1/m^3)$)

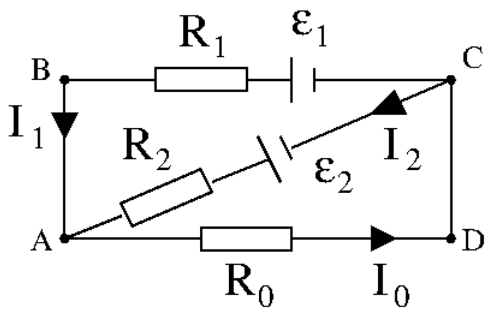
19. Which one is correct?
(a) Current is conserved here.
(b) Current densities are conserved.
(c) Electrons move faster in the output.
(d) Total resistance at the input is smaller compared to the one at the output.
(e) Drift velocities of electrons in one of the inputs and the output are the same.

20. What should be current density at the output?
(a) 2.0 A/m^2 (b) 4.0 A/m^2 (c) 0.5 A/m^2 (d) 0.25 A/m^2 (e) 1.0 A/m^2

21. What should be the ratio between the total input and output currents?
(a) 0.25 (b) 2 (c) 0.5 (d) 1 (e) 4

22. What should be the drift velocity (in m/s) of electrons at the output?
(a) 5.0 10^{-6} (b) 5.0 10^{-10} (c) 6.25 10^{-11} (d) 5.0 10^{-8} (e) 6.25 10^{-4}

Questions 23-25



An electric circuit with ϵ_1=12 V, ϵ_2=6V, $R_0 = 8\Omega$, $R_1 = 6\Omega$ and $R_2 = 3\Omega$ are given.

23. What is I_1 current in Amperes?
(a) 1 (b) 1/3 (c) 16/15 (d) 4/15 (e) 14/15

24. What is the magnitude of $(V_A - V_C)$ in Volts?
(a) 28/5 (b) 12 (c) 3 (d) 24/5 (e) 32/5

25. What is power dissipated through R_1 resistor in watts?
(a) 392/75 (b) 1/75 (c) 39/75 (d) 0 (e) 4/75

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ATTENTION: Each question has only one correct answer and is worth one point. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account.

For all questions take: Speed of light $c = 3 \times 10^8$ m/s, $\pi = 3$, $\epsilon_0 = 9 \times 10^{-12}$ C^2/N.m^2, electron charge $q_e = 1.6\ 10^{-19}$ C, electron mass $m_e = 9.11 \times 10^{-31}$ kg.

1. Electric field inside a hollow metallic charged sphere

(a) increases towards the center. (b) is zero. (c) is none of the other options. (d) depends on the total charge of the sphere. (e) decreases towards the center.

2. When a dielectric material is placed in an electric field, the field strength

(a) becomes infinite. (b) remains unchanged. (c) increases. (d) decreases. (e) reduces to zero.

3. A constant voltage source (a battery) is kept connected to a parallel plate capacitor before and after a dielectric material is inserted in between the plates. The dielectric constant of the material is $\kappa = 5$. What is the new electric field (after inserting the dielectric) when compared to the original field before inserting the dielectric?

(a) (1/5) times of the original one. (b) 5 times larger than the original one. (c) (1/25) times of the original one. (d) 25 times larger than the original one. (e) The same as the original one.

4. The electric field at a point located at a distance d from a straight charged conductor with length l (where $d \gg l$) is approximately

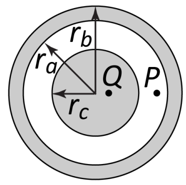
(a) inversely proportional to d. (b) proportional to d/l^2. (c) proportional to d^2. (d) proportional to d. (e) inversely proportional to d^2.

5. Unit of electric flux density is

(a) Weber/m^2 (b) Newton/Coulomb (c) Farad.m^2 (d) Farad (e) Weber

Questions 6-7

A very long, hollow metal cylinder has inner and outer radii of $r_a = 12$ cm and $r_b = 15$ cm, respectively. As shown in the figure, another very long, solid, uniformly charged insulating cylinder of radius $r_c = 5$ cm is located at the center of the hollow metal cylinder. The electric field at point P, a distance of $r_P = 10$ cm from the axis of the cylinders, is found to be $E_P = 3.6 \times 10^4$ N/C, directed radially outward. Take $k = 9 \times 10^9$ N.m^2/C^2.



6. Determine the total charge per unit length on the inner surface of the hollow metal cylinder.

(a) 2×10^{-7} C/m (b) -2×10^{-7} C/m (c) 1×10^{-8} C/m (d) 2×10^{-5} C/m (e) -2×10^{-5} C/m

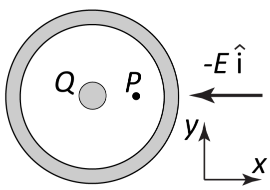
7. Determine the electric field at point Q, a distance of $r_Q = 1.25$ cm from the center of the solid insulating cylinder.

(a) 2.7×10^4 N/C (b) 3.6×10^4 N/C (c) 1.8×10^4 N/C (d) 7.2×10^4 N/C (e) 0.9×10^4 N/C

8. Two identical lightweight metal spheres are suspended near each other from insulating fibers. One sphere has a net charge; the other sphere has no net charge. The spheres will

(a) repel each other (b) attract each other (c) either attract or repel, depending on the sign of the charge on the charged sphere (d) start moving in a circle centered on their common center of mass (e) exert no net force on each other

9. A coaxial cable consist of a long, straight filament surrounded by a long, coaxial, cylindrical conducting shell (see figure). Assume charge Q is on the filament, zero net charge is on the shell, and the electric field is $E_1 \hat{\imath}$ at a particular point P midway between the filament and the inner surface of the shell. Next, you place the cable into a uniform external field $-E\hat{\imath}$ where $E_1 > E > 0$. What is the x-component of the total electric field at P then?



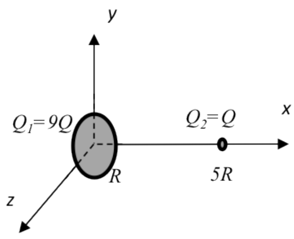
(a) $-E_1$ (b) Between 0 and E_1 (c) Between 0 and $-E_1$ (d) 0 (e) E_1

10. In a certain region of the space, the electric field is zero. From this fact, what can you conclude about the electric potential in this region?

(a) It has to be zero. (b) None of the other answers is necessarily true. (c) It has to be positive. (d) It does not vary with position. (e) It has to be negative.

Questions 11-15

A non-conducting solid sphere of radius R, uniformly charged with charge $Q_1 = 9Q$, is located at the center of the rectangular coordinate system. That is, the origin of the coordinate system coincides with the center of the sphere (shown in the figure on the right). Furthermore, a point-like charge, $Q_2 = Q$, is located at a distance $5R$ from the center of the sphere, as shown in the figure. Q is in c oulomb and R is in meter. The system is in vacuum and the dielectric constant of the non-conducting charged sphere is about 1.0, $\kappa \cong 1.0$ ($\epsilon = \kappa\epsilon_0 \approx \epsilon_0$)



11. What is the electric field vector at $x = R/2$?

(a) $\frac{721}{162}k\frac{Q}{R^2}(-\hat{\imath})$ (b) $\frac{729}{162}k\frac{Q}{R^2}(\hat{\imath})$ (c) $\frac{729}{162}k\frac{Q}{R^2}(-\hat{\imath})$ (d) $\frac{4}{81}k\frac{Q}{R^2}(\hat{\imath})$ (e) $\frac{721}{162}k\frac{Q}{R^2}(\hat{\imath})$

12. At what value of x does the electric field change its direction?

(a) $\frac{5R}{2}$ (b) $\frac{5R}{4}$ (c) $\frac{15R}{4}$ (d) $-R$ (e) 0

13. What is the electric field vector at the point $(0, 0, 5R)$?

(a) $\frac{kQ}{50R^2}(19\hat{k}-2\hat{\imath})$ (b) $\frac{kQ}{50R^2}(19\hat{k}+2\hat{\imath})$ (c) $\frac{kQ}{50R^2}\frac{\sqrt{2}}{2}[(18\sqrt{2}+1)\hat{k}-\hat{\imath}]$ (d) $\frac{2\sqrt{2}kQ}{50R^2}[(18\sqrt{2}-1)\hat{k}+\hat{\imath}]$ (e) $\frac{2\sqrt{2}kQ}{50R^2}[(18\sqrt{2}+1)\hat{k}-\hat{\imath}]$

14. What is the potential difference between the surface of the sphere and the position at $x = 3R$, $V(R, 0, 0) - V(3R, 0, 0)$?

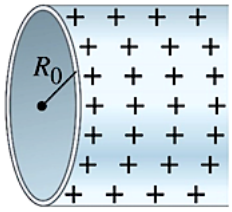
(a) $\frac{67}{2}k\frac{Q^2}{R}$ (b) $\frac{185}{20}k\frac{Q}{R}$ (c) $\frac{9}{5}k\frac{Q}{R}$ (d) $\frac{23}{4}k\frac{Q}{R}$ (e) -$\frac{9}{5}k\frac{Q}{R}$

15. If another point-like particle of charge Q is released from the point $(R, 0, 0)$ with a non-zero initial kinetic energy, what will be the difference in the final and initial kinetic energies of this particle when it reaches the point $(3R, 0, 0)$?

(a) $\frac{23}{4}k\frac{Q^2}{R^2}$ (b) $\frac{37}{4}k\frac{Q}{R}$ (c) $\frac{37}{4}k\frac{Q^2}{R^2}$ (d) $\frac{23}{4}k\frac{Q^2}{R}$ (e) $\frac{67}{2}k\frac{Q}{R}$

Questions 16-19

A long cylindrical shell of radius R_0 and length l ($R_0 \ll l$) has a uniform surface charge density σ (C/m^2).



16. What is the electric field outside the cylindrical shell?

(a) $\frac{\sigma r}{2R_0}$ (b) $\frac{\sigma}{2\pi\epsilon_0}(\frac{r}{R_0})^2$ (c) $\frac{\sigma R_0}{\epsilon_0 r}$ (d) $\frac{\sigma r}{2\pi\epsilon_0 R_0}$ (e) $\frac{\sigma r}{2\pi\epsilon_0 R_0^2}$

17. What is the electric field inside the cylindrical shell?

(a) 0 (b) $\frac{\sigma R_0}{\epsilon_0 r}$ (c) $\frac{\sigma r}{2R_0}$ (d) $\frac{\sigma r}{2\pi\epsilon_0 R_0}$ (e) $\frac{\sigma r}{2\pi\epsilon_0 R_0^2}$

18. The shell is at an electric potential V_0. What is the potential at a distance $r > R_0$ from the center of the shell?

(a) $V_0 - \frac{\sigma R_0}{2\pi\epsilon_0}\ln(\frac{R_0}{r})$ (b) $V_0 + \frac{\sigma R_0}{\epsilon_0}\ln(\frac{r}{R_0})$ (c) V_0 (d) $V_0 - \frac{\sigma R_0}{\epsilon_0}\ln(\frac{r}{R_0})$ (e) $V_0 - \frac{\sigma}{2\pi\epsilon_0}\ln(\frac{r}{R_0})$

19. The shell is at an electric potential V_0. What is the potential at a distance $r < R_0$ from the center of the shell?

(a) $\frac{\sigma R_0}{2\pi\epsilon_0}\ln(\frac{r}{R_0})$ (b) 0 (c) V_0 (d) $\frac{\sigma R_0}{2\pi\epsilon_0}\ln(\frac{R_0}{r})$ (e) $-V_0$

20. The functional form of the electric potential is given as $V(x, y, z) = Axy^2z$ where x, y, z are given in meters and A is a constant. Calculate the magnitude of the electric field in V/m at point (1,1,1) m.

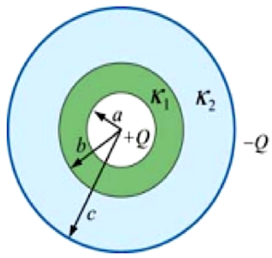
(a) $A\sqrt{5}$ (b) $2A$ (c) $A\sqrt{3}$ (d) $A\sqrt{6}$ (e) $3A$

21. The electric potential is given as $V(x, y, z) = Ay^2 - Bxy + Cx$ where A, B and C are positive constants. At which of the following points in space is the electric field equal to zero?

(a) $x = -B^2/2AC, y = -C/B, z = 0$ (b) $x = -A^2/2BC, y = -C/B, z = 0$ (c) $x = 2BC/A^2, y = -C/A, z = 0$ (d) $x = 2AC/B^2, y = C/B, z = 0$ (e) $x = -2AC/B^2, y = -C/A, z = 0$

Questions 22-25

The spherical capacitor shown in the figure consists of a solid metal core of radius $a = 10$ cm. Outside there is a non-conducting material with dielectric constant $\kappa_1 = 3$ up to the radius $b = 2a$ and another non-conducting material with $\kappa_2 = 2$ up to the radius $c = 3a$. The region from radius $r = 3a$ to $r = 4a$ is metal. The capacitor is connected to a battery of ε equal to 12 V. Assume that the charge on the inner conductor is Q and that the charge on the outer conductor is $-Q$, as shown in the figure.



22. What is the electric field inside the inner sphere and why?

(a) 0 since Ampere's law forbids it. (b) kQ/r because Coulomb's law requires it. (c) kQ/r^2 because Coulomb's law requires it. (d) kQ/r^2 because Gauss's law requires it. (e) 0 since there is no charge inside the solid metal core.

23. What is the electric field between $r = a$ and $r = 2a$ where the dielectric constant is $\kappa_1 = 3$?

(a) $Q/(4\pi\epsilon_0 r^2)$ (b) $Q/(16\pi\epsilon_0 a^2)$ (c) $Q/(12\pi\epsilon_0 a^2)$ (d) 0 (e) $Q/(12\pi\epsilon_0 r^2)$

24. Find the capacitance $C = Q/\varepsilon$ for this device.

(a) $16\pi/(\epsilon_0 a)$ (b) $16\pi\epsilon_0 a^2$ (c) $16\pi\epsilon_0 a$ (d) $16\pi\epsilon_0$ (e) $4\pi\epsilon_0 a$

25. Find the energy stored in the capacitor.

(a) $8\pi\epsilon_0 a\varepsilon^2$ (b) $16\pi\epsilon_0 a\varepsilon^2$ (c) 0 (d) $\varepsilon^2/(8\pi\epsilon_0 a)$ (e) $\varepsilon^2/(4\pi\epsilon_0 a)$

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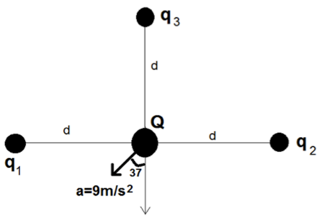
ATTENTION: Each question has only one correct answer and is worth one point. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account.

For all questions take: Speed of light $c = 3 \times 10^8$ m/s, $\pi = 3$, $\epsilon_0 = 9 \times 10^{-12}$ C^2/N.m^2, electron charge $q_e = 1.6\ 10^{-19}$ C.

Questions 1-3

Three point charges q_1, q_2, and q_3 are located in equal distances d = 1 m to the origin as shown in the figure. Another point charge Q = + 1 μC with mass m = 1 g is located at the origin and has an acceleration a = 9 m/s^2 with 37° angle to the y axis, as shown. (k = 9.109 Nm^2/C^2)



1. What are the sings of the charges?

(a) q_2 and q_3 are +, q_1 is − (b) q_2 and q_3 are −, q_1 is + (c) q_1 and q_3 are +, q_2 is − (d) q_1, q_2 and q_3 are − (e) q_1, q_2 and q_3 are +

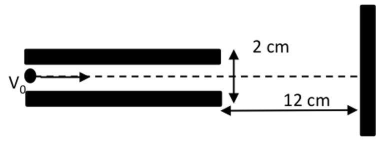
2. What is the magnitude of the net force acting on Q ?

(a) 9.0×10^{-3} N (b) 7.2 N (c) 7.2×10^{-3} N (d) 6.3×10^{-3} N (e) 9.0 N

3. What is the magnitude of charge of q_3 ?

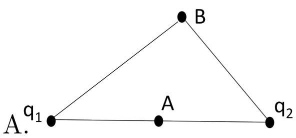
(a) 0.6 μC (b) 0.1 μC (c) 0.9 μC (d) 0.8 μC (e) 1.0 μC

4. In a cathode ray tube (CRT) of a computer monitor, an electron with an initial speed $v_0 = 6.6 \times 10^6$ m/s is projected along the axis midway between the deflection plates. The uniform electric field between the plate is 1000 V/m in upward direction. Gravitational force is negligible. How far below the axis has the electron moved when it reaches the end of the plates?



(a) 72 m (b) 8/108 m (c) 1/122 m (d) 8 m (e) 0.67 m

5. Two point charges q_1= 3 nC and q_2= -6 nC are 0.1 m apart. Point A is midway between them; point B is 0.08 m from q_1 and 0.06 m from q_2. Take the electric potential to be zero at infinity. Find the work done by the electric field on a charge of 2nC that travels from point B to A.

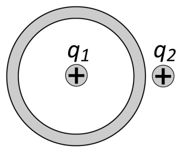


(a) 967 nJ (b) -0.29 nJ (c) 0.29 mJ (d) 1125 nJ (e) -145 nJ

6. A cubic Gaussian surface surrounds a very long, straight, charged filament that passes perpendicularly through two opposite faces of the surface. No other charges are nearby. Through how many of the cubic surface faces is the electric flux zero?

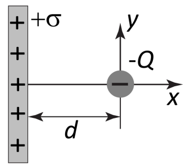
(a) It depends on the location of the filament relative to the Gaussian surface (b) 2 (c) 0 (d) 6 (e) 4

7. A hollow, conducting sphere is initially uncharged. A positive charge, $+q_1$, is placed into the cavity inside the sphere, as shown in the figure. Then, a second positive charge, $+q_2$, is placed near the sphere but outside it. Which of the following statements describes the net electric force on each charge?



(a) There is no net electric force on either charge. (b) There is a net electric force on $+q_2$ but not on $+q_1$. (c) Both charges feel a net electric force of the same magnitude and the same direction. (d) There is a net electric force on $+q_1$ but not on $+q_2$. (e) Both charges feel a net electric force of the same magnitude and opposite directions.

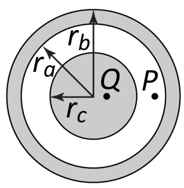
8. A very large nonconducting sheet with a positive uniform surface charge density $\sigma = +2.0\,\mu$C/m^2 is located at a distance $d = 0.2$ m from a negative point charge $Q = -12.0\,\mu$C. At what distance $x > 0$ (measured from the point charge) is the total electric field produced by both charge distributions zero? Take $\pi \approx 3$.



(a) 0.6 m (b) 0.1 m (c) 0.3 m (d) 1.2 m (e) 1 m

Questions 9-10

A hollow metal sphere has inner and outer radii of $r_a = 12$ cm and $r_b = 15$ cm, respectively. As shown in the figure, a solid, uniformly charged insulating sphere of radius $r_c = 5$ cm is located at the center of the hollow metal sphere. The electric field at point P, a distance of $r_P = 10$ cm from the center of the spheres, is found to be $E_P = 3.6 \times 10^4$ N/C, directed radially outward. Take $k = 9 \times 10^9\,$N.m^2/C^2.



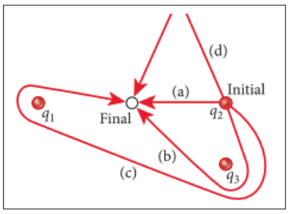
9. Determine the total charge on the inner surface of the hollow metal sphere.

(a) -4×10^{-7} C (b) -4×10^{-8} C (c) 1×10^{-8} C (d) 4×10^{-7} C (e) 4×10^{-8} C

10. Determine the electric field at point Q, a distance of $r_Q = 1.25$ cm from the center of the insulating sphere.

(a) 3.6×10^4 N/C (b) 14.4×10^4 N/C (c) 1.8×10^4 N/C (d) 5.4×10^4 N/C (e) 7.2×10^4 N/C

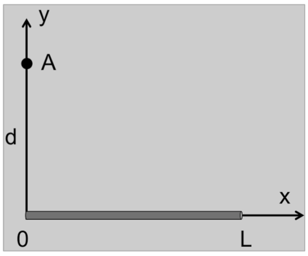
11. Three identical positive point charges are located at fixed points in space. Then charge q_2 is moved from its initial location to a final location as shown in the figure. Which path requires the least work?



(a) d (b) c (c) The work is the same for all the paths (d) b (e) a

Questions 12-15

A thin wire with length L = 4 m and a linear charge density given as a function of x by $\lambda = Ax$, is placed along x axis as shown in the figure. $k = 9 \times 10^9$ Vm/C and $A = 2 \times 10^{-9}$ C/m.



12. What is the electric potential (at point A) at a perpendicular distance d = 3 m from one end of the wire?

(a) 12 V (b) 18 V (c) 4 V (d) 36 V (e) 2 V

13. What is the potential energy of a point charge q = 3 nC placed at point A?

(a) 36 nJ (b) 3 nJ (c) 72 nJ (d) 12 nJ (e) 108 nJ

14. What is the y-component of the electric field due to the charged wire at point A?

(a) 7.2 V/m (b) 9 V/m (c) $72/\sqrt{13}$ V/m (d) $36/\sqrt{13}$ V/m (e) 12 V/m

15. The potential in a region of a plane is given as V = 2xy - 3y^2 Volt. What is the y-component of the electric field at a position of (2 m, 3 m)?

(a) 5 V/m (b) $15/\sqrt{13}$ V/m (c) 8 V/m (d) 14 V/m (e) 12 V/m

Questions 16-20

A coaxial cable (TV antenna cable) of length "l" consists of an inner metallic wire of radius "a", a plastic layer around it up to radius "$4a$", outer metal mesh up to radius "$5a$" and an outer plastic layer up to radius "$8a$". The dielectric constant of the plastic is "κ". The inner wire is attached to the positive and the outer mesh wire to the negative terminals of a battery so that a charge of $+Q$ has accumulated on the inner and $-Q$ on the outer wires.

16. What is the electric field at radius $r < a$ inside the inner conductor?

(a) $Q/2\pi\kappa\epsilon_0 l^2$ (b) Q/lr (c) $Q/4\pi\kappa\epsilon_0 r^2$ (d) $Q/2\pi\kappa\epsilon_0 lr$ (e) 0

17. What is the electric field in the plastic layer between the inner and outer conductors?

(a) $Q/2\pi\kappa\epsilon_0 lr$ (b) Q/lr (c) $Q/2\pi\kappa\epsilon_0 r^2$ (d) $Q/2\pi\kappa\epsilon_0 l^2$ (e) 0

18. What is the potential difference between the inner and outer conductors?

(a) $(Q/2\pi\kappa\epsilon_0 l)e^4 a$ (b) $3aQ/lr$ (c) $(Q/2\pi\kappa\epsilon_0 l)\ln 4$ (d) $(Q/2\pi\kappa\epsilon_0 l)(3a)$ (e) 0

19. What is the capacitance of the coaxial cable?

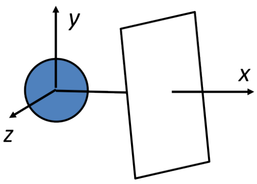
(a) $4\pi\kappa\epsilon_0 l/(\ln 4)$ (b) $l/2\pi\kappa\epsilon_0(\ln 4)$ (c) $2\pi\kappa\epsilon_0 l/(\ln 4)$ (d) 0 (e) $2\pi\kappa\epsilon_0 l/4$

20. What is the energy stored in the capacitor?

(a) $Q^2/4\pi\kappa\epsilon l$ (b) 0 (c) $Q^2 \ln 4/4\pi\kappa\epsilon_0 l$ (d) $Q^2/12\pi\kappa\epsilon_0 la$ (e) $3Q^2 a/4\pi\kappa\epsilon_0 l$

Questions 21-25

A conducting sphere of radius R=20 cm and an infinite non-conducting plane are located at the points (0,0,0) and (1m,0,0), respectively, as shown in figure. The system is in vacuum. The sphere is charged with $+Q = 2 \times 10^{-8}$ C. Positively charged plane has a surface charge density $\sigma = 18$ nC/m^2. Take $k = 9 \times 10^9$ Nm^{2}C^{-2}, charge of a proton $q = 1.6 \times 10^{-19}$ C, and $\epsilon_0 = 18 \times 10^{-12}$ C^2/ Nm^2



21. What is the net electric field (in N/C unit) at a distance x = 0.3 m between the sphere and the plane?

(a) $2000\hat{\imath}$ (b) $400(-\hat{\imath})$ (c) $1000\hat{\imath}$ (d) $400\hat{\imath}$ (e) $1000(-\hat{\imath})$

22. At which value of the x, in between the sphere and the plane, the net electric field change its direction?

(a) 0.36 m (b) 0.6 m (c) $\sqrt{0.72}$ m (d) $\sqrt{0.18}$ m (e) 0.4 m

23. At which value of the x the magnitude of the net electric field has its maximum value?

(a) 0 (b) -1.0 m (c) 1.0 m (d) -0.2 m (e) 0.2 m

24. What is the potential difference between the surface of the sphere and plane?

(a) -180 V (b) -80 V (c) 80 V (d) 1520 V (e) -1520 V

25. If a proton is set free from the surface of the sphere with initial kinetic energy K_1, what will be the change in the final and initial kinetic energies (in unit of Joule) of the proton when it reaches the plane; $K_2 - K_1$ =? (Give your result in terms of nano Joules)

(a) +2432 (b) +1284 (c) -128 (d) -2432 (e) -288

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ATTENTION: There is normally only one correct answer for each question and each correct answer is worth the same point. Only the answers on your answer sheet will be graded. Please be sure that you have marked all of your answers on the answer sheet by using a pencil (*not* pen).

If necessary $k = \frac{1}{4\pi\epsilon_0}$, $\epsilon_0 \approx 9 \times 10^{-12}\ C^2/Nm^2$

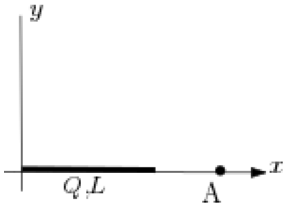
Questions 1-2

1. The magnitude of the electric force between the two charges does not depend on
(a) the distance between the charges (b) the sign of the charges (c) the magnitude of the charges (d) the dielectric constant of the medium (e) the distribution of charges

2. Which of the following has the unit of electric flux in the SI system?
(a) $kg.m^2/A.s^3$ (b) $kg^2.m/A.s^3$ (c) $kg.m^2/A.s^2$ (d) $kg.m^3/A.s^3$ (e) $kg^2.m^3/A.s^2$

Questions 3-6

A rod of length L and charge Q, which is uniformly distributed on the rod, is located on the x-axis, as shown in the figure. The coordinates of A is $(2L, 0)$.



3. What is the electric potential at A?
(a) $\frac{kQ}{L}\ln 3$ (b) $2\frac{kQ}{L}$ (c) $\frac{kQ}{L}\frac{1}{\ln 3}$ (d) $\frac{kQ}{L}\ln 2$ (e) $3\frac{kQ}{L}$

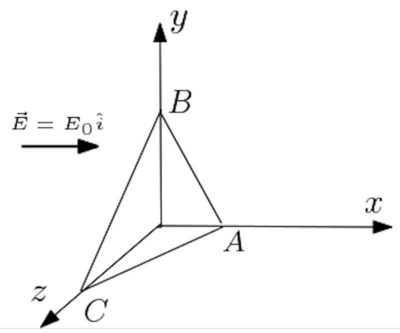
4. What is the magnitude of the electric field at A?
(a) $\frac{1}{2}\frac{kQ}{L^2}$ (b) $3\frac{kQ}{L^2}$ (c) $\frac{1}{3}\frac{kQ}{L^2}$ (d) $2\frac{kQ}{L^2}$ (e) $\frac{3}{2}\frac{kQ}{L^2}$

5. What is the work done **by the electric field** created by this rod to move a test charge of magnitude q from infinity to point A?
(a) $\frac{kQq}{L}\ln 3$ (b) $-\frac{1}{2}\frac{kQq}{L}$ (c) $\frac{kQq}{L}\ln 2$ (d) $-\frac{kQq}{L}\ln 3$ (e) $-\frac{kQq}{L}\ln 2$

6. If the charge density on the rod were $\lambda(x) = \alpha x$ where α is a constant and x is the distance from the origin, what would be the total charge on the rod?
(a) $\frac{3\alpha L^2}{2}$ (b) $\frac{\alpha L}{2}$ (c) $\frac{3\alpha L}{2}$ (d) αL (e) $\frac{\alpha L^2}{2}$

Questions 7-9

Consider a triangular prism located in a three-dimensional cartesian coordinate system, as shown in the figure. There is an external uniform electric field $\vec{E} = E_0\hat{i}$ and there is no charge inside the prism. The coordinates of the vertex points of the prism are: $A: (a, 0, 0)$, $B: (0, b, 0)$, and $C: (0, 0, c)$

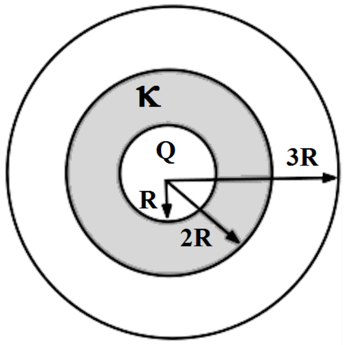


7. What is the total electric flux through the prism? (a) $-\frac{E_0ab}{2}$ (b) 0 (c) $\frac{E_0ab}{2}$ (d) $\frac{E_0bc}{2}$ (e) $-\frac{E_0bc}{2}$

8. What is the electric flux through the surface bounded by the points A, B, and C?
(a) $\frac{E_0ac}{2}$ (b) $-\frac{E_0ab}{2}$ (c) $\frac{E_0bc}{2}$ (d) 0 (e) $-\frac{E_0ac}{2}$

9. If the net electric flux through the prism were 3 Nm^2/C, what would be the amount of charge enclosed by the prism?
(a) $20 \times 10^{-12}\ C$ (b) $27 \times 10^{-12}\ C$ (c) $24 \times 10^{-12}\ C$ (d) $29 \times 10^{-12}\ C$ (e) $18 \times 10^{-12}\ C$

Questions 10-15



Consider the system shown in the figure: A spherical shell of radius R and charge Q is concentric with a neutral spherical **conductor** of inner radius $2R$ and outer radius $3R$, and the region between the spherical shell and the conductor is filled with a dielectric material of constant κ.

10. What is the magnitude of the electric field in the region $R < r < 2R$?

(a) $\frac{2kQ}{3\kappa r^2}$ (b) $\frac{2kQ}{\kappa r^2}$ (c) $\frac{kQ}{\kappa r^2}$ (d) $\frac{kQ}{2\kappa r^2}$ (e) $\frac{kQ}{3\kappa r^2}$

11. What is the magnitude of the electric field in the region $3R < r$?

(a) $\frac{2kQ}{3r^2}$ (b) $\frac{kQ}{2r^2}$ (c) $\frac{2kQ}{r^2}$ (d) $\frac{kQ}{r^2}$ (e) $\frac{kQ}{3r^2}$

12. What is the charge on the outer surface of the conductor at $r = 3R$?

(a) $3Q$ (b) $2Q$ (c) $-Q$ (d) $-2Q$ (e) Q

13. What is the electric potential in the conductor, assuming that the potential is zero at infinity?

(a) $\frac{kQ}{R}$ (b) $\frac{3kQ}{2R}$ (c) $\frac{2kQ}{3R}$ (d) $\frac{kQ}{2R}$ (e) $\frac{kQ}{3R}$

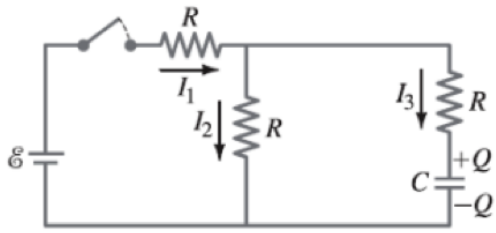
14. What would be the charge on the inner surface of the conductor if there were no dielectric material in the region $R < r < 2R$?

(a) $3Q$ (b) $2Q$ (c) $-3Q$ (d) $-2Q$ (e) $-Q$

15. What is the electrostatic energy stored in the dielectric region $R < r < 2R$?

(a) $\frac{kQ^2}{4\kappa^2 R}$ (b) $\frac{kQ^2}{3\kappa^2 R}$ (c) $\frac{kQ^2}{\kappa^2 R}$ (d) $\frac{2kQ^2}{3\kappa^2 R}$ (e) $\frac{3kQ^2}{4\kappa^2 R}$

Questions 16-20



Consider the RC-circuit shown in the figure, where all resistors have the same resistance R. The capacitor is initially uncharged and at $t = 0$ the switch is closed.

16. What is the current I_3 immediately after the switch is closed?

(a) $2\varepsilon/(3R)$ (b) $\varepsilon/(2R)$ (c) $\varepsilon/(4R)$ (d) 0 (e) $\varepsilon/(3R)$

17. What is the current I_3 as $t \to \infty$ after the switch is closed?

(a) 0 (b) $\varepsilon/(3R)$ (c) $\varepsilon/(4R)$ (d) $2\varepsilon/(3R)$ (e) $\varepsilon/(2R)$

18. What is the potential difference across the capacitor as $t \to \infty$ after the switch is closed?

(a) $\varepsilon/2$ (b) 0 (c) $2\varepsilon/3$ (d) $\varepsilon/4$ (e) $\varepsilon/3$

19. What is the amount of charge accumulated in the capacitor as a function of time when the switch is closed?

(a) $Q(t) = \frac{\varepsilon C}{3}\left[1 - e^{-2t/(3RC)}\right]$

(b) $Q(t) = \frac{2\varepsilon C}{3}\left[1 - e^{-2t/(3RC)}\right]$

(c) $Q(t) = \frac{\varepsilon C}{2}\left[1 - e^{-2t/(3RC)}\right]$

(d) $Q(t) = \frac{3\varepsilon C}{2}\left[1 - e^{-2t/(3RC)}\right]$

(e) $Q(t) = \frac{3\varepsilon C}{4}\left[1 - e^{-2t/(3RC)}\right]$

20. What is the time constant of the circuit when the switch is closed?

(a) $\frac{RC}{2}$ (b) $\frac{3RC}{4}$ (c) $\frac{2RC}{3}$ (d) $\frac{3RC}{2}$ (e) $\frac{RC}{3}$

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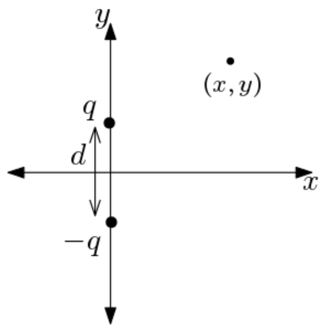
ATTENTION: Each question has only one correct answer and is worth one point. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account.

For all questions take: $k = 1/(4\pi\epsilon_0) \approx 9 \times 10^9$ N·m^2/C^2

Questions 1-3

Two point charges of magnitude $-q$ and q are located at points $(0, -d/2)$ and $(0, d/2)$, respectively, in a two dimensional xy-coordinate system as shown in the figure. This construction is known as the electric dipole of magnitude $p = qd$.



1. Which of the following is the electric potential created by this dipole at an arbitrary point (x, y)?

(a) $kq\left(\frac{1}{\sqrt{x^2+(y-d/2)^2}} - \frac{1}{\sqrt{x^2+(y-d/2)^2}}\right)$

(b) $kq\left(\frac{1}{\sqrt{x^2+(y-d/2)^2}} - \frac{1}{\sqrt{x^2+(y+d/2)^2}}\right)$

(c) $kq\left(\frac{1}{\sqrt{x^2+(y-d)^2}} + \frac{1}{\sqrt{x^2+(y+d)^2}}\right)$ (d) $kq\left(\frac{1}{\sqrt{x^2+(y-d/2)^2}} + \frac{1}{\sqrt{x^2+(y+d/2)^2}}\right)$

(e) $kq\left(\frac{1}{\sqrt{(x-d/2)^2+(y-d/2)^2}} - \frac{1}{\sqrt{(x-d/2)^2+(y+d/2)^2}}\right)$

2. Which of the following is the electric field vector created at the point $(d, 3d/2)$?

(a) $\frac{kq}{d^2}\left[\left(\frac{1}{2^{3/2}} + \frac{1}{5^{3/2}}\right)\hat{\imath} + \left(\frac{1}{2^{3/2}} + \frac{2}{5^{3/2}}\right)\hat{\jmath}\right]$

(b) $\frac{kq}{d^2}\left[\left(\frac{1}{2^{3/2}} - \frac{1}{5^{3/2}}\right)\hat{\imath} - \left(\frac{1}{2^{3/2}} - \frac{2}{5^{3/2}}\right)\hat{\jmath}\right]$ (c) $\frac{kq}{d^2}\left[\left(\frac{1}{2^{3/2}} - \frac{1}{5^{3/2}}\right)\hat{\imath} + \left(\frac{1}{2^{3/2}} - \frac{2}{5^{3/2}}\right)\hat{\jmath}\right]$ (d) $\frac{kq}{d^2}\left[\left(\frac{1}{2^{3/2}} - \frac{1}{5^{3/2}}\right)\hat{\imath} + \left(\frac{1}{2^{3/2}} + \frac{2}{5^{3/2}}\right)\hat{\jmath}\right]$

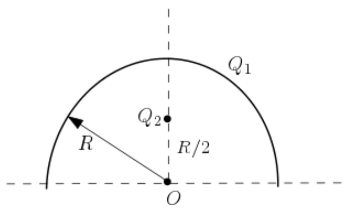
(e) $\frac{kq}{d^2}\left[\left(\frac{1}{2^{3/2}} + \frac{1}{5^{3/2}}\right)\hat{\imath} + \left(\frac{1}{2^{3/2}} - \frac{2}{5^{3/2}}\right)\hat{\jmath}\right]$

3. What is the work done by electric forces on a test charge Q to move it from the point $(4d, 0)$ to $(d, 3d/2)$?

(a) $\frac{kQq}{d}\left(\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{5}}\right)$ (b) $+\frac{kQq}{d}\left(\frac{1}{\sqrt{3}} - \frac{1}{\sqrt{5}}\right)$ (c) $-\frac{kQq}{d}\left(\frac{1}{\sqrt{2}} - \frac{1}{\sqrt{5}}\right)$ (d) $-\frac{kQq}{d}\left(\frac{1}{\sqrt{2}} - \frac{1}{\sqrt{3}}\right)$ (e) $\frac{kQq}{d}\left(\frac{1}{\sqrt{2}} - \frac{1}{\sqrt{3}}\right)$

Questions 4-5

A wire of charge Q_1 is bended into the shape of a semicircular wire of radius R, and located in a two dimensional xy-coordinate system as shown in the figure. A point charge of Q_2 is located at $(0, R/2)$ in this coordinate system.



4. What is $\frac{Q_2}{Q_1}$ if the electric potential at point O is zero?

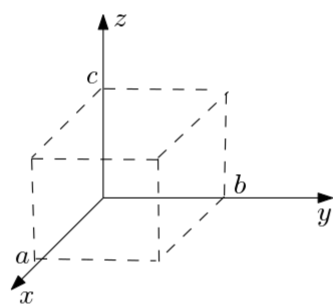
(a) $\frac{1}{3}$ (b) $-\frac{1}{3}$ (c) $\frac{1}{2}$ (d) $-\frac{1}{2}$ (e) -2

5. What is $\frac{Q_2}{Q_1}$ if the electric field at point O is zero?

(a) $\frac{1}{2}$ (b) -2 (c) $\frac{1}{3\pi}$ (d) $-\frac{\pi}{3}$ (e) $-\frac{1}{2\pi}$

Questions 6-8

Consider a region of the shape of a rectangular box in the three dimensional coordinate system shown in the figure.



6. Assuming that if there is no electric charge in the region and there is a uniform electric field of the form $\vec{E} = 3\hat{\imath} - 2\hat{\jmath}$, which of the following is the net electric flux through the region?

(a) $3ac$ (b) $2ab$ (c) $2ac$ (d) 0 (e) $3ab$

7. Assuming that there is an electric field of the form $\vec{E} = 2z\hat{k}$, which of the following is the total electric flux through this region?

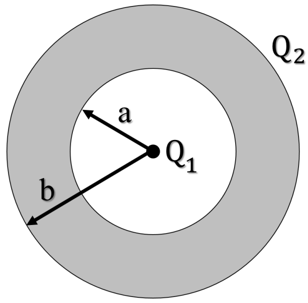
(a) $3abc$ (b) $2abc$ (c) $4abc$ (d) $3bc$ (e) $5abc$

8. For the electric field of the form $\vec{E} = 2z\hat{k}$, what is the amount of electric charge inside the box?

(a) $5\epsilon_0 abc$ (b) $3\epsilon_0 abc$ (c) $2\epsilon_0 abc$ (d) $4\epsilon_0 abc$ (e) $3\epsilon_0 bc$

Questions 9-13

A point charge Q_1 is located at the center of a thick metal shell of inner radius a and outer radius b as shown in the figure. The charge on the outer surface of the metal shell in this configuration is Q_2.



9. What is the total charge on inner surface ($r = a$) of the conducting spherical shell?

(a) Q_1 (b) $-Q_1$ (c) $-2Q_1 + Q_2$ (d) Q_2 (e) $Q_2 - Q_1$

10. What is the electric field at any point in the cavity inside the spherical shell? ($\vec{E}_{r<a}$ =?)

(a) $k\frac{2Q_1-Q_2}{r^2}\hat{r}$ (b) $k\frac{Q_1+Q_2}{r^2}\hat{r}$ (c) $k\frac{Q_2}{r^2}\hat{r}$ (d) $k\frac{Q_1-Q_2}{r^2}\hat{r}$ (e) $k\frac{Q_1}{r^2}\hat{r}$

11. What is the potential difference between a point at a distance $a/2$ from the center and a point on the outer surface of the conducting spherical shell? ($V(r = a/2) - V(r = b)$=?)

(a) $k\frac{Q_1+Q_2}{a}$ (b) $k\frac{Q_2}{a}$ (c) $k\frac{Q_1}{b}$ (d) $k\frac{Q_1}{a}$ (e) $k\frac{Q_2-Q_1}{b}$

12. What is the electric field at any point in the region $r > b$? ($\vec{E}_{r>b}$ =?)?

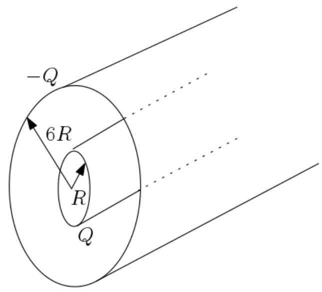
(a) $k\frac{2Q_1-Q_2}{r^2}\hat{r}$ (b) $k\frac{Q_1-Q_2}{r^2}\hat{r}$ (c) $k\frac{Q_1}{r^2}\hat{r}$ (d) $k\frac{Q_1+Q_2}{r^2}\hat{r}$ (e) $k\frac{Q_2}{r^2}\hat{r}$

13. What is the total energy stored in the electric field outside the spherical shell in the region $b < r < \infty$? ($U_{b<r<\infty}$ =?)

(a) $\frac{Q_2^2}{8\pi\epsilon_0 b}$ (b) $\frac{2Q_1^2-Q_2^2}{8\pi\epsilon_0 b}$ (c) $\frac{Q_1^2}{8\pi\epsilon_0 b}$ (d) $\frac{Q_2^2+Q_1^2}{8\pi\epsilon_0 a}$ (e) $\frac{Q_2^2-Q_1^2}{8\pi\epsilon_0 a}$

Questions 14-17

A cylindrical capacitor consists of two coaxial cylindrical metal shells as shown in the figure. The inner shell has radius R and charge Q and the outer shell has radius $6R$ and charge $-Q$. Both cylinders have length L which is assumed to be much greater than R.



14. Which of the following is the electric field in the region $6R > r > R$?

(a) $\frac{Q}{2\pi\epsilon_0 L^2}$ (b) $\frac{Q}{2\pi\epsilon_0 r^2}$ (c) $\frac{Q}{4\pi\epsilon_0 r^2}$ (d) $\frac{Q}{4\pi\epsilon_0 Lr}$ (e) $\frac{Q}{2\pi\epsilon_0 Lr}$

15. Which of the following is the potential difference between the shells?

(a) $\frac{Q\ln(3/2)}{4\pi\epsilon_0 L}$ (b) $\frac{Q\ln 5}{2\pi\epsilon_0 L}$ (c) $\frac{Q\ln 6}{2\pi\epsilon_0 L}$ (d) $\frac{Q\ln 6}{4\pi\epsilon_0 L}$ (e) $\frac{Q\ln(5/2)}{2\pi\epsilon_0 L}$

16. Which of the following is the capacitance of the system?

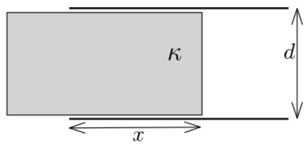
(a) $\frac{2\pi\epsilon_0 L}{\ln 5}$ (b) $\frac{4\pi\epsilon_0 L}{\ln 5}$ (c) $\frac{2\pi\epsilon_0 L}{\ln(3/2)}$ (d) $\frac{2\pi\epsilon_0 L}{\ln 6}$ (e) $\frac{4\pi\epsilon_0 L}{\ln(5/2)}$

17. If the region $3R > r > R$ is filled with a dielectric material of dielectric constant κ, which of the following is the capacitance of the system?

(a) $\frac{2\pi\kappa\epsilon_0 L}{\ln 3+\ln 2}$ (b) $\frac{2\pi\epsilon_0 L}{\kappa\ln 3+\kappa\ln 2}$ (c) $\frac{2\pi\kappa\epsilon_0 L}{\kappa\ln 3+\ln 2}$ (d) $\frac{2\pi\kappa\epsilon_0 L}{\ln 3+\kappa\ln 2}$ (e) $\frac{2\pi\epsilon_0 L}{\kappa\ln 3+\ln 2}$

Questions 18-20

Consider a parallel plate capacitor of capacitance C_0 connected to a battery of voltage V_0. The distance between the plates is d and each plate is a square of side L. A dielectric material of dielectric constant κ is inserted a distance x between the parallel plates of the capacitor as shown in the figure.



18. Which of the following is the capacitance as a function of x?

(a) $C_0\left(1 + (\kappa + 1)\frac{x}{L}\right)$ (b) $C_0\left(1 + \kappa\frac{x}{L}\right)$ (c) $C_0\left(1 + (\kappa - 1)\frac{x}{L}\right)$ (d) $C_0\left(1 + (2\kappa - 1)\frac{x}{L}\right)$
(e) $C_0\left(1 + (\kappa - 2)\frac{x}{L}\right)$

19. Assuming that the potential difference between the plates is kept constant (by keeping the voltage source in the system), which of the following is the energy stored in the capacitor after the dielectric is inserted? (U_0 is the stored energy before the dielectric material is inserted.)

(a) $U_0\left(1 + (\kappa - 1)\frac{x}{L}\right)$ (b) $U_0\left(1 + (\kappa + 1)\frac{x}{L}\right)$ (c) $U_0\left(1 + (\kappa - 2)\frac{x}{L}\right)$ (d) $U_0\left(1 + (2\kappa - 1)\frac{x}{L}\right)$ (e) $U_0\left(1 + \kappa\frac{x}{L}\right)$

20. Assuming that the charge on the capacitor is kept constant (by removing the battery after charging the plates and before the dielectric is inserted), which of the following is the energy stored in the capacitor after the dielectric is inserted? (U_0 is the stored energy before the dielectric material is inserted.)

(a) $\frac{U_0}{\left(1+(2\kappa-1)\frac{x}{L}\right)}$ (b) $\frac{U_0}{\left(1+(\kappa+1)\frac{x}{L}\right)}$ (c) $\frac{U_0}{\left(1+(\kappa-1)\frac{x}{L}\right)}$ (d) $\frac{U_0}{\left(1+\kappa\frac{x}{L}\right)}$ (e) $\frac{U_0}{\left(1+(\kappa-2)\frac{x}{L}\right)}$

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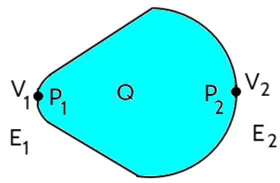
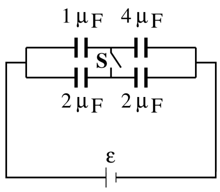
ATTENTION: Each question has only one correct answer and is worth one point. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account.

1. A charged metallic body is suspended in air, as shown in the figure. The electric potential and the magnitude of the electric field vector at a point P_1 of the body in air are V_1 and E_1, respectively. At a point P_2 in the figure, these quantities are V_2 and E_2. If the total charge of the body is positive, which one of the following is correct?



(a) $V_1 < V_2$ and $E_1 < E_2$ (b) $V_1 = V_2$ and $E_1 > E_2$ (c) $V_1 > V_2$ and $E_1 > E_2$
(d) $V_1 = V_2$ and $E_1 < E_2$ (e) $V_1 = V_2$ and $E_1 = E_2$

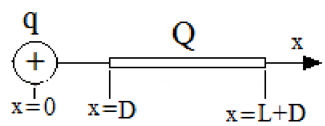
2. What is the ratio of equivalent capacitances for the cases where the switch is open and closed?



(a) $\frac{9}{10}$ (b) $\frac{5}{3}$ (c) $\frac{9}{40}$ (d) 1 (e) $\frac{3}{5}$

Questions 3-7

Positive charge Q is distributed non-uniformly on an insulating rod which lies along the x-axis from $x = D$ to $x = D + L$. Linear charge density of the rod is given as



$$\lambda = \begin{cases} 0 & 0 \le x \le D \\ \alpha x^2 & D \le x \le L + D \end{cases}$$

where α is a constant. A positive point charge q is placed at $x = 0$. (Here $\hat{\imath}$ is the unit vector parallel to positive x-axis)

3. Find α in terms of Q.

(a) $3Q/\left[(L+D)^3 - D^3\right]$ (b) $Q/\left[3(L+D)^3 - 3D^3\right]$ (c) Q/L^3 (d) $Q/\left[(L+D)^3 - 2D^3\right]$ (e) $3Q/(L+D)^3$

4. Which one of the following expressions give the electric field at $x = 0$ which is generated by the rod?

(a) $\frac{-\hat{\imath}\,\alpha}{4\pi\epsilon_o}\int_L^{L+D}\frac{dx}{x^2}$ (b) $\frac{-\hat{\imath}\,\alpha}{4\pi\epsilon_o}\int_L^{L+D}\frac{dx}{x}$ (c) $\frac{-\hat{\imath}\,\alpha}{4\pi\epsilon_o}\int_L^{L+D}dx$ (d) $\frac{-\hat{\imath}\,\alpha}{4\pi\epsilon_o}\int_0^{L}\frac{dx}{x^2}$ (e) $\frac{-\hat{\imath}\,\alpha}{4\pi\epsilon_o}\int_0^{L+D}\frac{dx}{x^2}$

5. Find the electric field generated by the rod at $x = 0$.

(a) $-\frac{(L+D)\alpha}{8\pi\epsilon_o L^2}\hat{\imath}$ (b) $-\frac{\alpha}{4\pi\epsilon_o(L+D)}\hat{\imath}$ (c) $-\frac{L^3\alpha}{4\pi\epsilon_o}\hat{\imath}$ (d) $-\frac{\alpha}{4\pi\epsilon_o L^2}\hat{\imath}$ (e) $-\frac{L\alpha}{4\pi\epsilon_o}\hat{\imath}$

6. Which one of the following is the force that the charge q exerts on the rod?

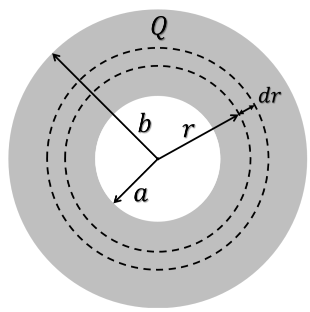
(a) $\frac{-L^3\alpha q}{4\pi\epsilon_o}\hat{\imath}$ (b) $\frac{\alpha q}{4\pi\epsilon_o(L+D)}\hat{\imath}$ (c) $\frac{\alpha q}{4\pi\epsilon_o L^2}\hat{\imath}$ (d) $\frac{(L+D)\alpha q}{8\pi\epsilon_o L^2}\hat{\imath}$ (e) $\frac{L\alpha q}{4\pi\epsilon_o}\hat{\imath}$

7. Assume that another positive point charge Q is placed R apart to the left of charge q. If the net force on q is zero, find the distance R?

(a) $\frac{2Q}{3\alpha L^2}$ (b) $\sqrt{\frac{3Q}{\alpha^2 L}}$ (c) $\sqrt{\frac{3Q}{2\alpha L^3}}$ (d) $\frac{Q}{\alpha L^2}$ (e) $\sqrt{\frac{Q}{\alpha L}}$

Questions 8-9

A solid spherical shell of inner radius a and outer radius $b = 2a$ has a uniform charge density and total charge Q. Assume, the sphere is constructed by adding successive layers of concentric shells of charge dq and of thickness dr. Take $V(\infty) = 0$.



8. When the outer radius is r $(a < r < b)$, how much energy (dU) is needed to add a spherical shell of thickness dr having a charge dq?

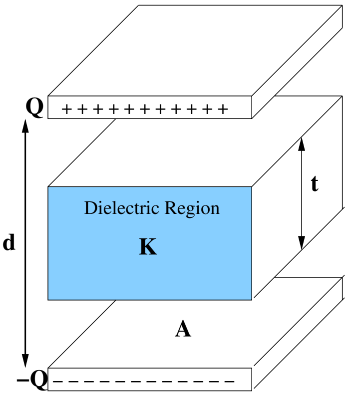
(a) $\frac{3Q^2 r(r^3 - a^3)\,dr}{74\pi\epsilon_o a^6}$ (b) $\frac{3Q^2 r(r^3 - a^3)\,dr}{188\pi\epsilon_o a^6}$ (c) $\frac{3Q^2 r(r^3 - a^3)\,dr}{86\pi\epsilon_o a^6}$ (d) $\frac{3Q^2 r(r^3 - a^3)\,dr}{196\pi\epsilon_o a^6}$
(e) $\frac{3Q^2 r(r^3 - a^3)\,dr}{176\pi\epsilon_o a^6}$

9. Find the energy (U) needed to assemble the total charge Q.

(a) $\frac{141Q^2}{740\pi\epsilon_o a}$ (b) $\frac{141Q^2}{1760\pi\epsilon_o a}$ (c) $\frac{141Q^2}{860\pi\epsilon_o a}$ (d) $\frac{141Q^2}{1960\pi\epsilon_o a}$ (e) $\frac{3Q^2}{40\pi\epsilon_o a}$

Questions 10-14

A non-conducting slab of thickness t, surface area A and dielectric constant K is inserted into space between the plates of a parallel plate capacitor with spacing d, charge Q and area A as shown in the figure. The slab is not necessarily halfway between the capacitor plates. ($\sqrt{A} \gg d$)



10. What is the magnitude of the electric field outside of the dielectric material and between the plates?

(a) $\dfrac{Q}{K\epsilon_o A}$ (b) $\dfrac{Qd}{t\epsilon_o A}$ (c) $\dfrac{Q}{\epsilon_o A}$ (d) $\dfrac{Q}{(K-1)\epsilon_o A}$ (e) $\dfrac{Qt}{d\epsilon_o A}$

11. What is the magnitude of the electric field in the dielectric region?

(a) $\dfrac{Qt^2}{K\epsilon_o A d^2}$ (b) $\dfrac{Q}{K\epsilon_o A}$ (c) $\dfrac{Qt}{dK\epsilon_o A}$ (d) $\dfrac{Qd}{tK\epsilon_o A}$ (e) $\dfrac{Q}{(K-1)\epsilon_o A}$

12. What is the absolute value of the potential difference between the plates?

(a) $\dfrac{Q}{K\epsilon_o A}\left[-d-t\left(1-\dfrac{1}{K}\right)\right]$ (b) $\dfrac{Q}{K\epsilon_o A}\left[d+t\left(1-\dfrac{1}{K}\right)\right]$ (c) $\dfrac{Q}{\epsilon_o A}\left[-d+t\left(-1-\dfrac{1}{K}\right)\right]$
(d) $\dfrac{Q}{K\epsilon_o A}\left[-d+t\left(1+\dfrac{1}{K}\right)\right]$ (e) $\dfrac{Q}{\epsilon_o A}\left[d-t\left(1-\dfrac{1}{K}\right)\right]$

13. What is the capacitance of this system?

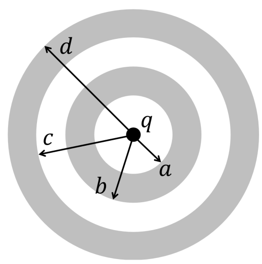
(a) $\dfrac{\epsilon_o A}{d-Kt}$ (b) $\dfrac{\epsilon_o A}{d-t[1+(1/K)]}$ (c) $\dfrac{\epsilon_o A}{d+t[1-(1/K)]}$ (d) $\dfrac{\epsilon_o A}{d-t[1-(1/K)]}$ (e) $\dfrac{\epsilon_o A}{d+Kt}$

14. What is the ratio of stored energy between the vacuum region and the dielectric region?

(a) K (b) $\dfrac{Kt}{d}$ (c) $\dfrac{K}{d-t}$ (d) $\dfrac{K(d-t)}{t}$ (e) $\dfrac{Kd}{t}$

Questions 15-18

A small conducting spherical shell with an inner radius a and outer radius b is concentric with a large conducting spherical shell with an inner c and outer radius d. The inner shell has total charge $3q$ and outer shell has charge $-4q$. A point-like particle of charge q is located at the common center of the two shells. Here $k = 1/(4\pi\epsilon_o)$.



15. Find the electric field (magnitude and direction) in terms of q and the distance of r from the center for $a < r < b$.

(a) zero (b) $k\dfrac{q}{r^2}$ outward (c) $k\dfrac{q}{r^2}$ inward (d) $k\dfrac{4q}{r^2}$ outward (e) $k\dfrac{2q}{r^2}$ outward

16. Find the electric field (magnitude and direction) in terms of q and the distance of r from the center for $b < r < c$.

(a) $k\dfrac{2q}{r^2}$ outward (b) $k\dfrac{3q}{r^2}$ inward (c) $k\dfrac{4q}{r^2}$ outward (d) $k\dfrac{q}{r^2}$ outward (e) zero

17. Find the electric field (magnitude and direction) in terms of q and the distance of r from the center for $r > d$.

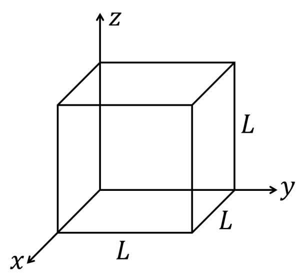
(a) $k\dfrac{q}{r^2}$ outward (b) $k\dfrac{3q}{r^2}$ outward (c) zero (d) $k\dfrac{4q}{r^2}$ outward (e) $k\dfrac{4q}{r^2}$ inward

18. What is the total charge on the inner surface of the outer shell at $r = c$?

(a) $-q$ (b) $+4q$ (c) $+3q$ (d) $-4q$ (e) $-3q$

Questions 19-20

A cube has sides of length $L = 0.5\,m$. It is placed with one corner at the origin as shown in the figure. The electric field is not uniform but is given by $\vec{E} = [4.0\ N/(C\cdot m)]y\hat{\jmath} - [2.0\ \mathrm{N/(C\cdot m)}]z\hat{k}$.
Take $\epsilon_o = 9\times 10^{-12}\ C^2/N\cdot m^2$ **.**



19. Find the total flux for the cube in $N\cdot m^2/C$'s.

(a) 0.5 (b) 0.125 (c) 0 (d) 0.25 (e) 1

20. Find the total electric charge (in coulombs) inside the cube?

(a) $1/9\times 10^{-12}$ (b) 2.25×10^{-12} (c) 4.5×10^{-12} (d) 1.125×10^{-12} (e) $1/18\times 10^{-12}$

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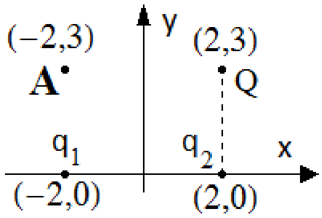
Student ID		Signature		

ATTENTION: Each question has only one correct answer and is worth one point. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account.

For all questions take $\frac{1}{4\pi\epsilon_o} = 9 \times 10^9 \; N\,m^2/C^2$.

Questions 1-5



Three point charges are placed at the following (x,y) coordinates: charge $q_1 = 9\,nC$ at $(-2\,m, 0)$, charge $q_2 = 5\,nC$ at $(2\,m, 0)$, and charge Q$= -8\,nC$ at $(2\,m, 3\,m)$. Take the zero of potential to be at infinity. (Unit prefix n stands for nano $= 10^{-9}$, $\hat{\imath}$ and $\hat{\jmath}$ are unit vectors pointing in positive x and y axes respectively).

1. Which of the following is the electrical force that Q exerts on q_2 in nN units?

(a) $72\,\text{nN}\hat{\imath}$ (b) $120\,\hat{\jmath}$ (c) $-40\,\hat{\jmath}$ (d) $40\,\hat{\jmath}$ (e) $-120\,\hat{\jmath}$

2. What is the electrical potential at point $\mathbf{A}(-2\,m, 3\,m)$ due to these three point charges?

(a) 9 V (b) 54 V (c) 15.3 V (d) 18 V (e) 6.3 V

3. Which of the following is the electric field in units of V/m at point $\mathbf{A}(-2\,m, 3\,m)$ due to the charges q_1 and Q only?

(a) $-4.5\,\hat{\imath} + 9\,\hat{\jmath}$ (b) $4.5\,\hat{\imath} - 6\,\hat{\jmath}$ (c) $4.5\,\hat{\imath} + 9\,\hat{\jmath}$ (d) $9\,\hat{\imath} + 6\,\hat{\jmath}$ (e) $-9\,\hat{\imath} + 9\,\hat{\jmath}$

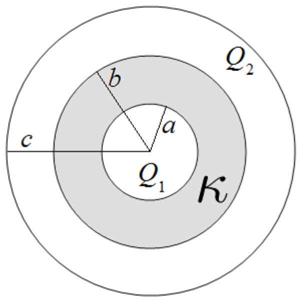
4. What is the potential at the (2 m,3 m) position of charge Q due to the charges q_1 and q_2?

(a) $72\,V$ (b) $-57.4\,V$ (c) $-18\,V$ (d) $14.4\,V$ (e) $-31.2\,V$

5. How much work is required to take the charge Q to infinity?

(a) $249.6\,J$ (b) $115.2\,J$ (c) $144\,J$ (d) $58.6\,J$ (e) $-576\,J$

Questions 6-10



A spherical capacitor consists of two concentric spherical conductors and a dielectric material filling the space between the conductors. The inner conductor is a solid sphere of radius $a = 2\,\text{cm}$, the outer one is a spherical shell whose inner and outer radii are $b = 6\,\text{cm}$ and $c = 10\,\text{cm}$ respectively. Dielectric constant of the material between the conductors $\kappa = 3$. The total charge on the inner conductor $Q_1 = 20\,pC$ and that on the outer one $Q_2 = 40\,pC$. In the following, r represents the distance from the center of the spheres. (Unit prefix p stands for pico $= 10^{-12}$).

6. How much charge accumulates on the outermost surface?

(a) $-60\,pC$ (b) $-20\,pC$ (c) $60\,pC$ (d) 0 (e) $-40\,pC$

7. What is the potential on the inner surface of the outer conductor, namely at r$=$ 6 cm?

(a) 6 V (b) 5.4 V (c) 9 V (d) 0 (e) 3.6 V

8. What is the capacitance of the system?

(a) $10\,pF$ (b) $40\,pF$ (c) $54\,pF$ (d) $60\,pF$ (e) $12\,pF$

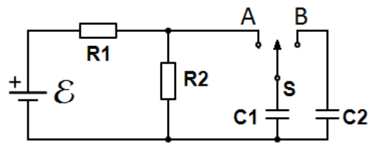
9. What is energy stored between the conductors?

(a) $30\,pJ$ (b) $20\,pJ$ (c) $54\,pJ$ (d) $45\,pJ$ (e) 0

10. What is total energy stored in the electric field outside the system where $c < r < \infty$?

(a) $18\,pJ$ (b) $162\,pJ$ (c) 0 (d) $72\,pJ$ (e) $54\,pJ$

Questions 11-15



The capacitors are initially uncharged and the battery has no internal resistance in the circuit given in the figure. $\mathcal{E} = 12\,\text{V}$, $C_1 = 50\,\mu\text{F}$, $C_2 = 100\,\mu\text{F}$, $R_1 = 2\,k\Omega$ and $R_2 = 4\,k\Omega$. (Unit prefixes μ, m and k stands for micro $= 10^{-6}$, milli $= 10^{-3}$ and kilo $= 10^3$ respectively).

11. What is the current flowing through the resistor R_1 immediately after the switch S is moved to position A?

(a) $3\,mA$ (b) $6\,mA$ (c) $1\,mA$ (d) $2\,mA$ (e) $4\,mA$

12. What is the potential difference across the capacitor C_1 long time after the switch S is moved to position A?

(a) 6 V (b) 0 V (c) 4 V (d) 8 V (e) 2 V

13. Which of the following is the time dependence of the charge stored in the capacitor C_1 in microcoulombs, assuming the switch S is moved to position A at t= 0?

(a) $200(1-e^{-12000t})$ (b) $100(1-e^{-30000t})$ (c) $300(1-e^{-5000t})$ (d) $500(1-e^{-1000t})$ (e) $400(1-e^{-15000t})$

Questions 14-15

At the instant when the potential difference across the capacitor C_1 is 6 V one moves the switch S to position B.

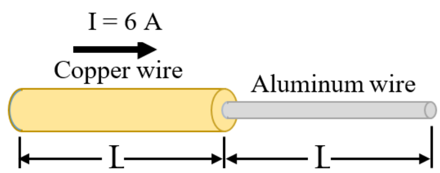
14. What is the potential difference across the capacitor C_2 after the circuit reaches equilibrium?

(a) 6 V (b) 9 V (c) 3 V (d) 2 V (e) 4 V

15. After the circuit reaches equilibrium, what is the total potential energy stored in the capacitors?

(a) $900\,\mu J$ (b) $450\,\mu J$ (c) $600\,\mu J$ (d) $200\,\mu J$ (e) $300\,\mu J$

Questions 16-20



A copper wire has a cross sectional area $A_1 = 10^{-6}\,m^2$ and has a density of charge carriers of 10^{29} electrons/m^3. As shown in the figure, the copper wire is attached to an equal length of aluminum wire with a cross sectional area $A_2 = 3 \times 10^{-8}\,m^2$, and density of charge carriers of 5×10^{28} electrons/m^3. A current of 6 A flows through the copper wire. Approximate resistivities of copper and aluminum are $\rho_{Cu} = 2 \times 10^{-8}\,\Omega.m$ and $\rho_{Al} = 3 \times 10^{-8}\,\Omega.m$ respectively.

16. Which of the following is the current flowing through the aluminum wire?

(a) 200 A (b) 0.18 A (c) 6 A (d) 1.2 A (e) 0.005 A

17. What is the ratio of the current densities in the two wires, J_{Cu}/J_{Al}?

(a) 3 (b) 0.0009 (c) 1 (d) 67 (e) 0.03

18. What is the ratio of the drift velocities in the two wires, v_D^{Cu}/v_D^{Al}?

(a) 0.015 (b) 67 (c) 0.03 (d) 3 (e) 0.0009

19. What is the ratio of the resistances of the two wires, R_{Cu}/R_{Al}?

(a) 3 (b) 1 (c) 0.02 (d) 50 (e) 1/3

20. What is the magnitude of the electric field in the copper wire?

(a) 0 (b) 0.12 V/m (c) 10^6 V/m (d) 9×10^9 V/m (e) 60 V/m

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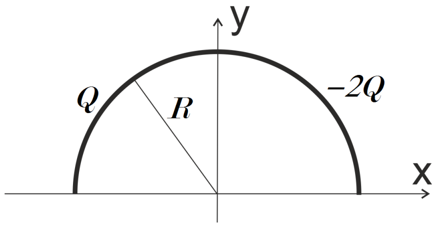
Questions 1-2

Positive charge Q for x<0 and negative charge $-2Q$ for x>0 is uniformly distributed around a semi-circle of radius R as shown in the figure.



1. Find the x-component of the electric field at the center of curvature.

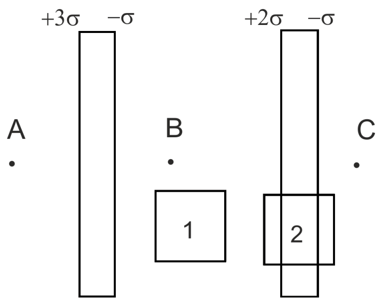
(a) $\frac{3kQ}{\pi R^2}$ (b) $\frac{6kQ}{\pi R^2}$ (c) $\frac{4kQ}{\pi R^2}$ (d) $\frac{kQ}{\pi R^2}$ (e) $\frac{2kQ}{\pi R^2}$

2. Find the y-component of the electric field at the center of curvature.

(a) $\frac{kQ}{\pi R^2}$ (b) $\frac{2kQ}{\pi R^2}$ (c) $\frac{3kQ}{\pi R^2}$ (d) $\frac{6kQ}{\pi R^2}$ (e) $\frac{4kQ}{\pi R^2}$

Questions 3-7

The surfaces of two thin nonconducting large planes are charged uniformly with different surface charge densities as shown in the figure.



3. Find the magnitude of the electric field at point A

(a) $\frac{3\sigma}{2\epsilon_o}$ (b) $\frac{3\sigma}{\epsilon_o}$ (c) $\frac{\sigma}{\epsilon_o}$ (d) $\frac{2\sigma}{\epsilon_o}$ (e) $\frac{\sigma}{2\epsilon_o}$

4. Find the magnitude of the electric field at point B

(a) $\frac{2\sigma}{\epsilon_o}$ (b) $\frac{3\sigma}{2\epsilon_o}$ (c) $\frac{3\sigma}{\epsilon_o}$ (d) $\frac{\sigma}{\epsilon_o}$ (e) $\frac{\sigma}{2\epsilon_o}$

5. Find the magnitude of the electric field at point C

(a) $\frac{3\sigma}{2\epsilon_o}$ (b) $\frac{3\sigma}{\epsilon_o}$ (c) $\frac{\sigma}{\epsilon_o}$ (d) $\frac{2\sigma}{\epsilon_o}$ (e) $\frac{\sigma}{2\epsilon_o}$

6. What is the flux through a cube (1) if the cube with a side length of b is placed between large planes (two surfaces of the cube are parallel to the plane).

(a) 0 (b) $\frac{3\sigma b^2}{\epsilon_o}$ (c) $\frac{3\sigma b^2}{2\epsilon_o}$ (d) $\frac{2\sigma b^2}{\epsilon_o}$ (e) $\frac{\sigma b^2}{\epsilon_o}$

7. What is the flux through a cube (2) if the cube is placed on the right plane so that the cube contains both faces of the plane (two surfaces of the cube are parallel to the plane).

(a) $\frac{3\sigma b^2}{\epsilon_o}$ (b) $\frac{\sigma b^2}{2\epsilon_o}$ (c) $\frac{\sigma b^2}{\epsilon_o}$ (d) $\frac{3\sigma b^2}{2\epsilon_o}$ (e) $\frac{2\sigma b^2}{\epsilon_o}$

Questions 8-9

An isolated conductor of arbitrary shape has a net charge of $10\,\mu C$. Inside the conductor there is a cavity within which there is a point charge of $3\,\mu C$.

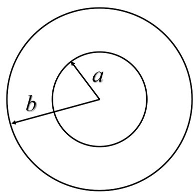
8. What is the charge on the cavity wall?

(a) 0 (b) $3\,\mu C$ (c) $-3\,\mu C$ (d) $7\,\mu C$ (e) $13\,\mu C$

9. What is the charge on the outer surface of the conductor?

(a) $-13\,\mu C$ (b) $13\,\mu C$ (c) $-3\,\mu C$ (d) $7\,\mu C$ (e) 0

10. Consider a conducting spherical shell with an inner radius a and outer radius b. If the space between two surfaces (surface a and surface b) be filled with a dielectric material of dielectric constant κ. What is the capacitance of this capacitor?



(a) $\frac{1}{4\pi\epsilon_o\kappa}\frac{ab}{b-a}$ (b) $4\pi\epsilon_o\kappa\frac{b-a}{ab}$ (c) $\frac{4\pi\epsilon_o}{\kappa}\frac{b-a}{ab}$ (d) $\frac{\kappa}{4\pi\epsilon_o}\frac{ab}{b-a}$ (e) $4\pi\epsilon_o\kappa\frac{ab}{b-a}$

Questions 11-12

A uniformly charged conducting sphere of 1 m radius has a surface charge density of $8\,\mu C/m^2$. Take $\pi = 3$ and $\epsilon_o = 9 \times 10^{-12}\, C^2/Nm^2$.

11. Find the net charge on the sphere, in units of μCs.

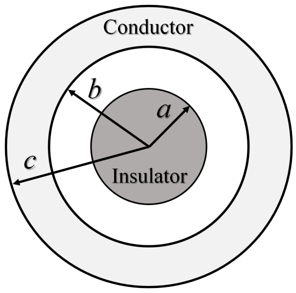
(a) 6 (b) 0 (c) 24 (d) 8 (e) 96

12. What is the total electric flux just outside surface of the sphere?

(a) $1.64 \times 10^6\, Nm^2/C$ (b) 0 (c) $8 \times 10^6\, Nm^2/C$ (d) $10.6 \times 10^6\, Nm^2/C$ (e) $0.1 \times 10^6\, Nm^2/C$

Questions 13-15

An insulating ball of dielectric constant κ and radius a carries a charge Q_1 and this charge is distributed non-uniformly with a volume charge density of the form $\rho(r) = \alpha r^2$ (here α is a constant). Then the ball is surrounded by a conducting spherical shell of inner radius b and outer radius c. The charge of the shell is Q_2. Find the magnitude of the electric field for the following regions:



13. $r < a$

(a) $\frac{\alpha r^3}{5\kappa\epsilon_o}$ (b) 0 (c) $\frac{\alpha r^3}{5\epsilon_o}$ (d) $\frac{\alpha r^5}{5\kappa\epsilon_o}$ (e) $\frac{\alpha a^3}{5\kappa\epsilon_o}$

14. $a < r < b$

(a) 0 (b) $\frac{2Q_1}{4\pi\kappa\epsilon_o r^2}$ (c) $\frac{Q_1}{4\pi\epsilon_o r^2}$ (d) $\frac{Q_1}{\kappa\epsilon_o r^2}$ (e) $\frac{Q_1}{4\pi\kappa\epsilon_o r^2}$

15. $b < r < c$

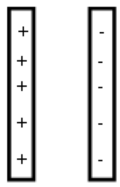
(a) 0 (b) $\frac{Q_1}{4\pi\kappa\epsilon_o r^2}$ (c) $\frac{Q_1}{4\pi\epsilon_o r^2}$ (d) $\frac{(Q_2-Q_1)}{4\pi\kappa\epsilon_o r^2}$ (e) $\frac{Q_1}{4\pi\kappa\epsilon_o (b-c)^2}$

16. Which of the following arguments are true?
I. The external work done to increase the plate separation of a parallel-plate capacitor is positive.
II. If the potential difference across a capacitor is tripled the stored energy decreases to 1/3 of its initial value
III. The presence of a dielectric increases the maximum operating voltage of a capacitor.

(a) I,II (b) I, III (c) II,III (d) I,II,III (e) II

Questions 17-18

Two parallel plates are charged with opposite charges as in figure. The separation between the plates is 0.020 m. Charge of the electron is $-1.6 \times 10^{-19}\, C$, charge of the proton is $+1.6 \times 10^{-19}\, C$. Answer the following two questions



17. If an electron is accelerated, from the negatively charged plate to the positively charged plate, through a potential difference 20 V what will be the change in electric potential energy of the electron in unit of Joule? Is it increasing or decreasing?

(a) $+1.25 \times 10^{+18}$, decreasing (b) -3.2×10^{-19}, decreasing (c) $+3.2 \times 10^{-18}$, increasing (d) -3.2×10^{-18}, decreasing (e) $-1.25 \times 10^{+20}$, increasing

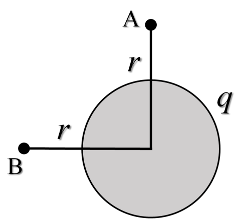
18. If the magnitude of the electric field between the plates is 500 Volt/meter. What is the change in potential energy of the proton, in unit of Joule, when accelerated from the positively charged plate to the negatively charged plate.

(a) 1.6×10^{-18} (b) $-6.25 \times 10^{+19}$ (c) -6.25×10^{-19} (d) -1.6×10^{-18} (e) $6.25 \times 10^{+19}$

19. If you increase the charge on a parallel-plate capacitor from $3\,\mu C$ to $9\,\mu C$ and increase the plate separation from 1 mm to 3 mm, the energy stored in the capacitor changes by a factor of

(a) $\frac{1}{3}$ (b) 8 (c) 9 (d) 27 (e) 3

20. Find the potential difference between points A and B, V_{AB} in terms of k, q, and r for a spherical charge distribution with charge q, as shown in figure.



(a) $\frac{kq}{2\sqrt{2}r}$ (b) $\frac{kq}{r}$ (c) 0 (d) $\frac{2kq}{r^2}$ (e) $\frac{kq}{\sqrt{2}r^2}$

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E-mail				

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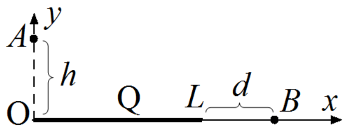
Unit prefixes $M = 10^6,\ k = 10^3,\ m = 10^{-3},\ \mu = 10^{-6},\ n = 10^{-9},\ p = 10^{-12}$

Questions 1-4



Positive charge Q is distributed uniformly on an insulating rod which lies along the $x-$axis from $x = 0$ to $x = L$. In the following $\not{k} = \dfrac{1}{4\pi\epsilon_o}$.

1. Which of the following gives the magnitude of the x component of the electric field at point A?

(a) $\frac{\not{k}\,Q}{L}\int_0^L \frac{x\,dx}{(x+h)^2}$ (b) $\frac{\not{k}\,Q}{L}\int_0^L \frac{x\,dx}{(x^2+h^2)^{3/2}}$ (c) $\frac{\not{k}\,Q}{L}\int_0^L \frac{x\,dx}{x^2+h^2}$ (d) $\frac{\not{k}\,Q}{L}\int_0^L \frac{dx}{(x^2+h^2)^{3/2}}$ (e) $\frac{\not{k}\,Q\,h}{L}\int_0^L \frac{dx}{(x^2+h^2)^{3/2}}$

2. Which of the following gives the magnitude of the y component of the electric field at point A?

(a) $\frac{\not{k}\,Q}{L}\int_0^L \frac{x\,dx}{(x^2+h^2)^{3/2}}$ (b) $\frac{\not{k}\,Q}{L}\int_0^L \frac{dx}{(x^2+h^2)^{3/2}}$ (c) $\frac{\not{k}\,Q\,h}{L}\int_0^L \frac{dx}{x^2+h^2}$ (d) $\frac{\not{k}\,Q\,h}{L}\int_0^L \frac{dx}{(x+h)^2}$ (e) $\frac{\not{k}\,Q\,h}{L}\int_0^L \frac{dx}{(x^2+h^2)^{3/2}}$

3. Which of the following gives the electric potential at point A? Assume V(∞)= 0.

(a) $\frac{\not{k}\,Q}{L}\int_0^L \frac{x\,dx}{\sqrt{x^2+h^2}}$ (b) $\frac{\not{k}\,Q\,h}{L}\int_0^L \frac{dx}{\sqrt{x^2+h^2}}$ (c) $\frac{\not{k}\,Q}{L}\int_0^L \frac{x\,dx}{(x^2+h^2)^2}$ (d) $\frac{\not{k}\,Q}{L}\int_0^L \frac{dx}{\sqrt{x^2+h^2}}$ (e) $\frac{\not{k}\,Q}{L}\int_0^L \frac{dx}{x^2+h^2}$

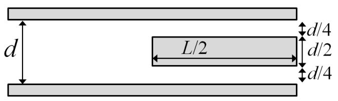
4. How much work does the electric field of this charge distribution do on a negative point charge q to bring it from ∞ to the point B?

(a) $\frac{2\,\not{k}\,q\,Q}{L+2\,d}$ (b) $\frac{\not{k}\,q\,Q\,L}{(x^2+d^2)^{3/2}}$ (c) $\frac{\not{k}\,q\,Q}{\sqrt{x^2+d^2}}$ (d) $\frac{\not{k}\,q\,Q}{L}\ln\frac{L+d}{d}$ (e) $\frac{\not{k}\,q\,Q}{L+d}$

Questions 5-7

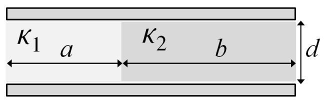
Consider a parallel plate capacitor of capacitance C_0. The distance between the plates is d and each plate is a square of side L.

5. If a conductor of thickness $d/2$ of width $L/2$ and of length L, is inserted between the plates of the capacitor as shown in the figure what will be the new capacitance?



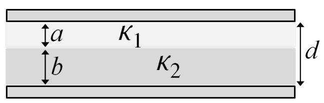
(a) $\dfrac{3\,C_0}{2}$ (b) $\dfrac{3\,C_0}{5}$ (c) $\dfrac{5\,C_0}{2}$ (d) $\dfrac{2\,C_0}{3}$ (e) $\dfrac{5\,C_0}{3}$

6. If two dielectric materials of dielectric constants κ_1 and κ_2 are inserted between the plates of the capacitor as shown in the figure what will be the new capacitance? Here $a + b = L$.



(a) $\dfrac{L\,\kappa_1\,\kappa_2}{a\,\kappa_2 + b\,\kappa_1}C_0$ (b) $\dfrac{L\,\kappa_1\,\kappa_2}{a\,\kappa_1 + b\,\kappa_2}C_0$ (c) $\dfrac{L\,(\kappa_1 + \kappa_2)}{a + b}C_0$ (d) $\dfrac{a\,\kappa_1 + b\,\kappa_2}{L}C_0$ (e) $\dfrac{a\,\kappa_2 + b\,\kappa_1}{L}C_0$

7. If two dielectric materials of dielectric constants κ_1 and κ_2 are inserted between the plates of the capacitor as shown in the figure what will be the new capacitance? Here $a + b = d$.



(a) $\dfrac{a + b}{d\,(\kappa_1 + \kappa_2)}C_0$ (b) $\dfrac{a\,\kappa_2 + b\,\kappa_1}{d}C_0$ (c) $\dfrac{d\,\kappa_1\,\kappa_2}{a\,\kappa_2 + b\,\kappa_1}C_0$ (d) $\dfrac{d\,\kappa_1\,\kappa_2}{a\,\kappa_1 + b\,\kappa_2}C_0$ (e) $\dfrac{a\,\kappa_1 + b\,\kappa_2}{d}C_0$

Questions 8-9

A 10 V power supply is connected to the terminals of a parallel plate capacitor of capacitance 60 μF.

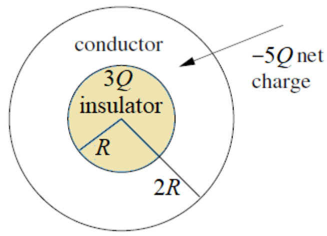
8. Without removing the power supply, the space between the plates is filled with an insulator of dielectric constant $\kappa = 4$. Which of the following is the energy stored in the capacitor after the insulator is inserted?

(a) 12 mJ (b) 6 mJ (c) 3 mJ (d) 1.5 mJ (e) 0.75 mJ

9. Assume that after fully charging the 60 μF capacitor the power supply is disconnected and the space between the plates is filled with an insulator of dielectric constant $\kappa = 4$. Which of the following is the energy stored in the capacitor after the insulator is inserted?

(a) 1.5 mJ (b) 0.75 mJ (c) 3 mJ (d) 12 mJ (e) 6 mJ

Questions 10-14



$3Q$ charge is uniformly distributed through a solid insulating sphere with radius R. This sphere is surrounded with an equicentered conducting spherical shell carrying $-5Q$ net charge and the thickness of it is given as R. If r is the distance measured from the center; (In the following $\not{k} = \frac{1}{4\pi\epsilon_o}$)

10. What is the charge density on the outer surface of the conducting sphere?

(a) $\frac{-Q}{8\pi R^2}$ (b) $\frac{-5Q}{16\pi R^2}$ (c) $\frac{-3Q}{16\pi R^2}$ (d) 0 (e) $\frac{-3Qr}{16\pi R^3}$

11. What are the electric fields for $r > 2R$, $R < r < 2R$ and $r < R$ regions, respectively?

(a) $\frac{-2\not{k}Q}{r^2}, 0, \frac{3\not{k}Qr}{R^3}$ (b) $\frac{-\not{k}Q}{r^2}, 0, \frac{3\not{k}Q}{R^2}$ (c) $\frac{-\not{k}Q}{r^2}, \frac{-2\not{k}Q}{r^2}, \frac{3\not{k}Qr}{R^3}$ (d) $\frac{-\not{k}Q}{r^2}, \frac{-5\not{k}Q}{4R^2}, \frac{3\not{k}Qr}{R^3}$ (e) $\frac{-\not{k}Q}{r^2}, 0, 0$

12. What are the electric potentials for $R < r < 2R$ and $r < R$ regions, respectively? Assume V(∞)= 0.

(a) $\frac{-\not{k}Q}{R}, \frac{-\not{k}Q}{2R}$ (b) $\frac{-\not{k}Q}{2R}, \frac{\not{k}Q}{2R}$ (c) $\frac{-\not{k}Q}{R}, \frac{\not{k}Q}{2R}(1 - 3\frac{r^2}{R^2})$ (d) $0, \frac{\not{k}Q}{2R}(5 - 6\frac{r^2}{R^2})$ (e) $\frac{-\not{k}Q}{2R}, \frac{\not{k}Q}{2R}(5 - 6\frac{r}{R})$

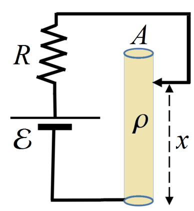
13. How much work is done to bring $-Q$ charge from the outer surface to the inner surface of the conducting shell?

(a) $\frac{2\not{k}Q^2}{r}$ (b) $\frac{-\not{k}Q^2}{r}$ (c) 0 (d) $\frac{-2\not{k}Q^2}{r}$ (e) $\frac{\not{k}Q^2}{r}$

14. If the charge in the inner sphere was concentrated at the center as a point charge instead of distributing throughout its volume, which one of the following would change?

(a) Electric potential for $r > 2R$ (b) Electric field for $r < R$ region (c) The work done to bring -Q charge from the outer surface to the inner surface of the conducting shell (d) Electric field for $R < r < 2R$ region (e) Charge densities on the inner and outer surfaces of the conducting shell

Questions 15-17



An ideal battery whose EMF is $\mathcal{E}$ is connected to a resistor with resistance R and a resistor with variable resistance as shown in the figure. The variable resistor is made up of a cylinder of cross sectional area A , and the material has resistivity ρ. The distance of the contact point from the end x can be adjusted to change the value of the resistance.

15. What is the current in the circuit in terms of the given quantities?

(a) $\frac{3A\mathcal{E}}{RA+2\rho x}$ (b) $\frac{2A\mathcal{E}}{RA+\rho x}$ (c) $\frac{A\mathcal{E}}{2RA}$ (d) $\frac{A\mathcal{E}}{RA+\rho x}$ (e) $\frac{3A\mathcal{E}}{2RA+\rho x}$

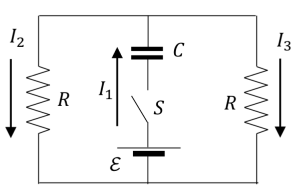
16. What is the power dissipated on the variable resistor?

(a) $\frac{3\rho A\mathcal{E}^2 x}{(2RA+\rho x)^2}$ (b) $\frac{3\rho A\mathcal{E}^2 x}{(RA+2\rho x)^2}$ (c) $\frac{2\rho A\mathcal{E}^2 x}{(RA+\rho x)^2}$ (d) $\frac{\rho A\mathcal{E}^2 x}{4R^2A^2}$ (e) $\frac{\rho \mathcal{E}^2 Ax}{(RA+\rho x)^2}$

17. What should be the value of x so that the power dissipated on the variable resistor is maximum?

(a) $\frac{2RA}{3\rho}$ (b) $\frac{2RA}{\rho}$ (c) $\frac{RA}{\rho}$ (d) $\frac{RA}{3\rho}$ (e) $\frac{3RA}{2\rho}$

Questions 18-20



Consider the circuit shown in the figure with the capacitor initially uncharged. The switch S is closed at time $t = 0$.

18. What is the current through each resistor at time $t = 0$?

(a) $I_1 = \frac{\mathcal{E}}{2R}, I_2 = I_3 = \frac{\mathcal{E}}{R}$ (b) $I_1 = I_2 = \frac{\mathcal{E}}{R}, I_3 = \frac{2\mathcal{E}}{R}$ (c) $I_1 = I_2 = \frac{2\mathcal{E}}{R}, I_3 = \frac{\mathcal{E}}{R}$
(d) $I_1 = 0, I_2 = I_3 = \frac{2\mathcal{E}}{R}$ (e) $I_1 = \frac{2\mathcal{E}}{R}, I_2 = I_3 = \frac{\mathcal{E}}{R}$

19. What is the final charge on the capacitor when it becomes fully charged?

(a) $2C\mathcal{E}$ (b) $C\mathcal{E}$ (c) $4C\mathcal{E}$ (d) $3C\mathcal{E}$ (e) 0

20. Find the current I_1 through the capacitor as a function of time.

(a) $\frac{\mathcal{E}}{2R}e^{-t/(RC)}$ (b) $\frac{2\mathcal{E}}{R}e^{-t/(RC)}$ (c) $\frac{\mathcal{E}}{2R}e^{-t/(RC/2)}$ (d) $\frac{2\mathcal{E}}{R}e^{-t/(2RC)}$ (e) $\frac{2\mathcal{E}}{R}e^{-t/(RC/2)}$

Group Number		Name		Type
List Number		Surname		A
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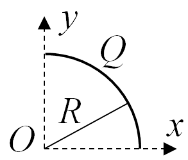
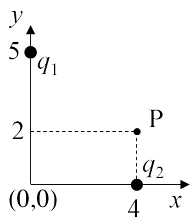
ATTENTION: Each question has only one correct answer. Be sure to fill in completely the circle that corresponds to your answer on the answer sheet. Use a pencil (not a pen). Only the answers on your answer sheet will be taken into account.

Questions 1-6



1. Charge Q is uniformly distributed over a thin quarter ring of radius R as shown in the figure. Which of the following is the magnitude of the electric field at point O?

(a) $\dfrac{2Q}{\pi^2\epsilon_0 R^2}$ (b) $\dfrac{Q}{4\pi^2\epsilon_0 R^2}$ (c) $\dfrac{Q}{\sqrt{2}\pi^2\epsilon_0 R^2}$ (d) $\dfrac{Q}{4\pi\epsilon_0 R}$ (e) $\dfrac{Q}{4\pi\epsilon_0 R^2}$



2. Two point charges q_1 and q_2 are placed at points (0 m, 5 m) and (4 m, 0 m), respectively, as shown in the figure. $q_1 = 25$ nC, $q_2 = 4$ nC. Find the electric field in N/C's at point P(4 m, 2 m) due to these charges. Take $k = 1/(4\pi\epsilon_0) = 9 \times 10^9$ Nm^2/C^2.

(a) $7.2\hat{\imath} + 3.6\hat{\jmath}$ (b) $7.2\hat{\imath} + 14.4\hat{\jmath}$ (c) $3.6\hat{\imath} - 7.2\hat{\jmath}$ (d) $7.2\hat{\imath} + 1.8\hat{\jmath}$ (e) $5.4\hat{\imath} - 3.6\hat{\jmath}$

3. Two non-conducting uniformly charged identical spheres having the same total charge are seperated by a distance. Each one experiences a force of magnitude F_0. Half of the charge on one sphere is then moved to the other without changing the distance between the spheres and keeping the uniformity of the charge distribution. What is the magnitude of the force between the spheres now?

(a) $3F_0/2$ (b) $3F_0/4$ (c) $2F_0$ (d) $9F_0/4$ (e) $F_0/2$

4. A positive point charge is released from rest in an electric field experiencing only the electric force. At any later time, the acceleration of the point charge

(a) is directly opposite the direction of the electric field at the position of the point charge.
(b) is in the direction of the electric field at the position of the point charge.
(c) is zero.
(d) is perpendicular to the direction of the electric field at the position of the point charge.
(e) can not be decided with the information given.

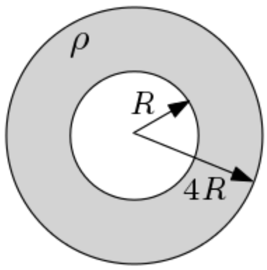
5. For which of the following charge distributions would Gauss's law not be **useful** for calculating the electric field?

(a) an infinite planar sheet having constant surface charge density
(b) a spherical shell of radius R with charge uniformly distributed over its surface
(c) a right circular cylinder of radius R and height h with charge uniformly distributed over its surface
(d) an infinitely long right circular cylinder of radius R with charge uniformly distributed over its surface
(e) a uniformly charged sphere of radius R

6. Consider a spherical insulator of radius R that has uniform charge distribution. Find the flux through a spherical surface of radius $R/2$ centered at the center of the sphere in terms of total charge Q of the sphere.

(a) $Q/(8\epsilon_0)$ (b) 0 (c) $Q/8$ (d) $Q/(4\epsilon_0)$ (e) $Q/4$

Questions 7-10



A thick spherical shell of inner radius R and outer radius $4R$, made of an insulator with dielectric constant $\kappa = 2$, has a uniform free charge density ρ. ($k \equiv \frac{1}{4\pi\epsilon_0}$, where ϵ_0 is the permittivity of the vacuum.)

7. What is the magnitude of the electric field at $r = 6R$?

(a) $\frac{5\rho R}{11\epsilon_0}$ (b) $\frac{7\rho R}{12\epsilon_0}$ (c) $\frac{9\rho R}{22\epsilon_0}$ (d) $\frac{7\rho R}{19\epsilon_0}$ (e) $\frac{5\rho R}{16\epsilon_0}$

8. What is the magnitude of the electric field at $r = 2R$?

(a) $\frac{7\rho R}{24\epsilon_0}$ (b) $\frac{9\rho R}{22\epsilon_0}$ (c) $\frac{5\rho R}{16\epsilon_0}$ (d) $\frac{7\rho R}{19\epsilon_0}$ (e) $\frac{5\rho R}{11\epsilon_0}$

9. What is the electric potential at $r = 6R$?
(Take the value of the potential at infinity zero, $V(\infty) = 0$.)

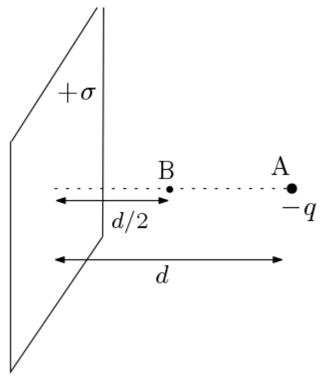
(a) $\frac{7\rho R^2}{2\epsilon_0}$ (b) $\frac{9\rho R^2}{4\epsilon_0}$ (c) $\frac{9\rho R^2}{2\epsilon_0}$ (d) $\frac{7\rho R^2}{8\epsilon_0}$ (e) $\frac{7\rho R^2}{4\epsilon_0}$

10. What is the electric potential at $r = 0$, at the center of the sphere?
(Take the value of the potential at infinity zero, $V(\infty) = 0$.)

(a) $\frac{21\rho R^2}{2\epsilon_0}$ (b) $\frac{51\rho R^2}{8\epsilon_0}$ (c) 0 (d) $\frac{47\rho R^2}{4\epsilon_0}$ (e) $\frac{39\rho R^2}{8\epsilon_0}$

Questions 11-13

A small test charge $-q$ is located at point A, at a distance d from a uniformly charged infinitely large nonconducting sheet, as shown in the figure. The charge is released from rest. The surface charge density of the sheet is $+\sigma$.



11. The point B is at a distance $d/2$ from the sheet. What is the potential difference between the points A and B, $V_A - V_B$, due to the large sheet?

(a) $\frac{\sigma d}{6\epsilon_0}$ (b) $-\frac{\sigma d}{6\epsilon_0}$ (c) $-\frac{\sigma d}{8\epsilon_0}$ (d) $\frac{\sigma d}{4\epsilon_0}$ (e) $-\frac{\sigma d}{4\epsilon_0}$

12. What is the work done by the electrostatic force while the test charge $-q$ moves from A to B?

(a) $-\frac{\sigma qd}{4\epsilon_0}$ (b) $\frac{\sigma qd}{6\epsilon_0}$ (c) $-\frac{\sigma qd}{6\epsilon_0}$ (d) $\frac{\sigma qd}{4\epsilon_0}$ (e) 0

13. What is the speed of the point charge at B? The mass of the test charge is m.

(a) $\sqrt{\frac{3\sigma qd}{2m\epsilon_0}}$ (b) $\sqrt{\frac{3\sigma qd}{5m\epsilon_0}}$ (c) $\sqrt{\frac{\sigma qd}{5m\epsilon_0}}$ (d) $\sqrt{\frac{\sigma qd}{6m\epsilon_0}}$ (e) $\sqrt{\frac{\sigma qd}{2m\epsilon_0}}$

Questions 14-20

Two concentric spherical conducting shells are separated by vacuum. The inner shell has total charge Q=$72\pi\times10^{-12}$C and radius a=5 cm, and the outer shell has charge $-Q$ and radius b=10 cm. Take $\epsilon_0 = 9 \times 10^{-12}$ F/m.

14. What is the potential difference between the conducting shells?

(a) 10 V (b) 15 V (c) 5 V (d) 20 V (e) 25 V

15. What is the potential difference between the inner conducting shell and a point at $r = 8$ cm from the center?

(a) 10 V (b) 25 V (c) 5 V (d) 15 V (e) 20 V

16. What is the capacitance of this capacitor?

(a) 0.9π pF (b) 7.2π pF (c) 1.8π pF (d) 0.4π pF (e) 3.6π pF

17. What is the potential energy stored in the capacitor?

(a) 360π pJ (b) 720π pJ (c) 90π pJ (d) 45π pJ (e) 180π pJ

The space between the conducting shells is filled with a dielectric material of the dielectric constant $\kappa = 2$.

18. What is the induced bound charge density on the dielectric at $r = a$?

(a) -7.2 nC/m^2 (b) -3.6 nC/m^2 (c) 0.45 nC/m^2 (d) -1.8 nC/m^2 (e) 0.9 nC/m^2

19. What is the change in the stored potential energy in the capacitor?

(a) 90π pJ (b) 45π pJ (c) 360π pJ (d) 720π pJ (e) 180π pJ

20. If the region between the conductors is filled with a dielectric of $\kappa = 2$ only between $r = 5$ cm and $r = 8$ cm, what is the capacitance of this new system?

(a) $0.72\pi\epsilon_0$ F (b) $0.64\pi\epsilon_0$ F (c) $1.44\pi\epsilon_0$ F (d) $0.36\pi\epsilon_0$ F (e) $0.32\pi\epsilon_0$ F