1. Two very large, nonconducting plastic sheets, each 10 cm thick, carry uniform charge densities \( \sigma_1, \sigma_2, \sigma_3, \) and \( \sigma_4 \) on their surfaces as shown in the figure. These surface charge densities have the values (in \( \mu\text{C/m}^2 \)): \( \sigma_1 = -6 \), \( \sigma_2 = 4 \), \( \sigma_3 = 2 \), and \( \sigma_4 = -1 \). Find the magnitude of the electric field at point B, far from the edges of these sheets.

(1) \( 1.7 \times 10^5 \text{ N/C} \)
(2) \( 5.6 \times 10^4 \text{ N/C} \)
(3) \( 2.8 \times 10^5 \text{ N/C} \)
(4) \( 7.3 \times 10^5 \text{ N/C} \)
(5) \( 0 \text{ N/C} \)

2. Two very large, nonconducting plastic sheets, each 10 cm thick, carry uniform charge densities \( \sigma_1, \sigma_2, \sigma_3, \) and \( \sigma_4 \) on their surfaces as shown in the figure. These surface charge densities have the values (in \( \mu\text{C/m}^2 \)): \( \sigma_1 = -6 \), \( \sigma_2 = 4 \), \( \sigma_3 = 2 \), and \( \sigma_4 = -1 \). Find the magnitude of the electric field at point A, far from the edges of these sheets.

(1) \( 5.6 \times 10^4 \text{ N/C} \)
(2) \( 1.7 \times 10^5 \text{ N/C} \)
(3) \( 2.8 \times 10^5 \text{ N/C} \)
(4) \( 7.3 \times 10^5 \text{ N/C} \)
(5) \( 0 \text{ N/C} \)
3. A very small object with mass $8 \times 10^{-9}$ kg and positive charge $6 \times 10^{-9}$ C is projected directly toward a very large insulating sheet of positive charge that has a uniform surface charge density of $5 \times 10^{-8}$ C/m². The object is initially 0.5 m from the sheet, and its initial speed is 40 m/s. What is the distance of closest approach to the sheet?

(1) 0.12 m  (2) 0.21 m  (3) 0.31 m  (4) 0.38 m  (5) 0 m

4. A hollow, conducting sphere with an outer radius of 0.5 m and an inner radius of 0.25 m has a uniform surface charge density of $+3 \times 10^{-6}$ C/m². A charge of $-3 \mu$C is now introduced into the center of the cavity inside the sphere. Calculate the magnitude of the electric field just outside the sphere.

(1) $2.3 \times 10^5$ N/C  (2) $4.5 \times 10^5$ N/C  (3) $3.4 \times 10^5$ N/C  (4) $1.1 \times 10^5$ N/C  (5) 0 N/C

5. What is the net enclosed charge in the shown cube if the electric field is given by $\vec{E} = 4 \hat{i} + (y - 2) \hat{j}$ and the cube has a side length of 4?

(1) $64 \epsilon_0$  (2) 0  (3) $4 \epsilon_0$  (4) $128 \epsilon_0$  (5) $32 \epsilon_0$

6. What is the net enclosed charge in the shown cube if the electric field is given by $\vec{E} = 4 \hat{i} + 2(y - 2) \hat{j}$ and the cube has a side length of 4?

(1) $128 \epsilon_0$  (2) 0  (3) $4 \epsilon_0$  (4) $64 \epsilon_0$  (5) $32 \epsilon_0$

7. Two identical raindrops, each with a radius of 1 mm and a charge of $-2.8 \times 10^{-12}$ C, collide and merge into one larger and spherical raindrop. What is the potential at the surface of this merged raindrop if its charge is distributed over its volume?

(1) $-40$ V  (2) $-25$ V  (3) $-50$ V  (4) $-20$ V  (5) $-12.5$ V

8. Two identical raindrops, each with a radius of 1 mm and a charge of $-1.4 \times 10^{-12}$ C, collide and merge into one larger and spherical raindrop. What is the potential at the surface of this merged raindrop if its charge is distributed over its volume?

(1) $-20$ V  (2) $-25$ V  (3) $-50$ V  (4) $-40$ V  (5) $-12.5$ V

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

(1) $x = 2AC/B^2$, $y = C/B$, $z = 0$
(2) $x = 0$, $y = 0$, $z = 0$
(3) $x = A/(B - C)$, $y = 1$, $z = 0$
(4) $x = -2BC/A^2$, $y = -C/A$, $z = 0$
(5) $x = -2AC/B^2$, $y = -C/B$, $z = 0$
10. How much work is required (as measured in eV) to assemble three electrons into an equilateral triangle with a side length of $10^{-9}$ m? The electrons are initially separated infinitely far from one another.

(1) 4.3 eV (2) 1.4 eV (3) $4 \times 10^9$ eV (4) $2.3 \times 10^{-19}$ eV (5) 2.9 eV

11. A charged glass rod is bent into the shape of a semicircle of radius $R$ and has a linear charge density of $\lambda$. What is the potential at point C at the center of the semicircle? (Take $V = 0$ infinitely far away.)

(1) $\lambda/(4\epsilon_0)$ (2) $\lambda/(4\pi\epsilon_0R)$ (3) $-\lambda/(2\pi\epsilon_0R)$ (4) $\lambda/(2\epsilon_0)$ (5) 0

12. Three particles are fixed on the $x$ axis. Particle 1 of charge $q_1$ is at $x = -a$, and particle 2 of charge $q_2$ is at $x = +a$. If their net electrostatic force on particle 3 of charge $+Q$ is to be zero, what must be the ratio $q_1/q_2$ when particle 3 is at $x = 1.5a$?

(1) $-25$ (2) $-9$ (3) $-1$ (4) $+9$ (5) $+25$

13. Three identical conducting spheres initially have the following charges: sphere A, $+4Q$; sphere B, $-6Q$; and sphere C, 0. Sphere A and B are fixed in place with a center-to-center separation that is much larger than the spheres. Two experiments are conducted. In experiment 1, sphere C is touched to sphere A and then (separately) to sphere B, and then it is removed. In experiment 2, starting with the same initial states, the procedure is reversed: sphere C is touched to sphere B and then (separately) to sphere A, and then it is removed. What is the ratio of the electrostatic force between A and B at the end of experiment 2 to that at the end of experiment 1?

(1) $3/8$ (2) $8/3$ (3) $1/1$ (4) $4/1$ (5) $1/4$

14. Four particles form a square as shown. The charges are $q_1 = q_4 = Q$ and $q_2 = q_3 = q$. What is $Q/q$ if the net electrostatic force on particles 1 and 4 is zero?

(1) $-\sqrt{8}$ (2) $+\sqrt{8}$ (3) $-2$ (4) $+2/2$ (5) $-1$

15. The figure shows a plastic ring of radius $R = 50.0$ cm. Two small charged beads are on the ring. Bead 1 of charge $+2.00 \mu$C is fixed in place at the left side; bead 2 of charge $+6.00 \mu$C can be moved along the ring. The two beads produce a net electric field of magnitude $E = 2.00 \times 10^5$ N/C at the center of the ring. What is the angle $\theta$ in degrees?

(1) 67.8 (2) 22.2 (3) 20.7 (4) 69.3 (5) 53.1
16. The figure shows three circular arcs centered on the origin. On each arc, the uniformly distributed charge is given in terms of $Q = 2.00 \, \mu C$. The radii are given in terms of $R = 10.0 \, \text{cm}$. What is the value of the $x$ component of the electric field (in $10^6 \, \text{N/C}$) at the origin?

- (1) $+1.14$
- (2) $-1.14$
- (3) 0
- (4) $+1.80$
- (5) $-1.80$

17. A nonconducting rod of length $L = 8.15 \, \text{cm}$ has a charge $-q = 4.23 \, \text{fC}$ uniformly distributed along its length. What is the magnitude of the electric field (in $10^{-3} \, \text{N/C}$) produced at point $P$ a distance $a = 12.0 \, \text{cm}$ from the rod?

- (1) 1.57
- (2) 0.94
- (3) 2.64
- (4) 8.23
- (5) 2.64

18. The line labelled 1 on figure (a) gives the charge $q$ that can be stored on capacitor 1 versus the electric potential $V$ set up across it. The vertical scale is set by $q_s = 16.0 \, \mu C$, and the horizontal scale is set by $V_s = 2.0 \, \text{V}$. The lines labelled 2 and 3 are similar plots for capacitors 2 and 3, respectively. Figure (b) shows a circuit with these three capacitors and a $6.0 \, \text{V}$ battery. What is the charge (in $\mu C$) stored on capacitor 2 in that circuit?

- (1) 12
- (2) 24
- (3) 16
- (4) 32
- (5) 8

19. The parallel plates in a capacitor, with plate area of $8.50 \, \text{cm}^2$ and an air-filled separation of $3.00 \, \text{mm}$, are charged by a $6.00 \, \text{V}$ battery. They are then disconnected from the battery and pulled apart (without discharge) to a separation of $8.00 \, \text{mm}$. Neglecting fringing, what is the potential difference between the plates?

- (1) 16 \, \text{V}
- (2) 6 \, \text{V}
- (3) 2 \, \text{V}
- (4) 12 \, \text{V}
- (5) 8 \, \text{V}

20. The space between two concentric conducting spherical shells of radii $b = 1.70 \, \text{cm}$ and $a = 1.20 \, \text{cm}$ is filled with a substance of dielectric constant $\kappa = 23.5$. A potential difference of $V = 73.0 \, \text{V}$ is applied across the inner and outer shells. What is the free charge (in $\mu C$) on the inner shell?

- (1) 7.78
- (2) 7.45
- (3) 0.33
- (4) 2.29
- (5) 3.24

21. A $9.00 \, \text{V}$ battery is connected to a resistive strip that consists of three sections with the same cross-sectional areas but different conductivities. The graph shows the electric potential $V(x)$ versus position $x$ along the strip. The horizontal scale is set by $x_s = 8.00 \, \text{mm}$. Section 3 has conductivity $3.00 \times 10^7 \, (\Omega\text{m})^{-1}$. What is the conductivity of section 1 in units of $10^7 \, (\Omega\text{m})^{-1}$?

- (1) 6
- (2) 4
- (3) 1
- (4) 2
- (5) 1/2

22. A certain wire has resistance $R$. What is the resistance of a second wire, made of the same material, that is half as long and has half the diameter?

- (1) $2R$
- (2) $R$
- (3) $R/2$
- (4) $4R$
- (5) $R/4$
23. Wire $C$ and $D$ are made from different materials and have length $L_C = L_D = 1.0$ m. The resistivity and diameter of wire $C$ are $2.0 \times 10^{-6}$ Ωm and 1.00 mm, and those of wire $D$ are $1.0 \times 10^{-6}$ Ωm and 0.50 mm. The wires are joined as shown, and a current of 2.0 A is set up in them. What is the rate at which energy is dissipated in wire $C$?

(1) 10 W (2) 20 W (3) 8 W (4) 32 W (5) 16 W

**FOLLOWING GROUPS OF QUESTIONS WILL BE SELECTED AS ONE GROUP FROM EACH TYPE**

**TYPE 1**
Q# S 1
Q# S 2

**TYPE 2**
Q# S 5
Q# S 6

**TYPE 3**
Q# S 7
Q# S 8