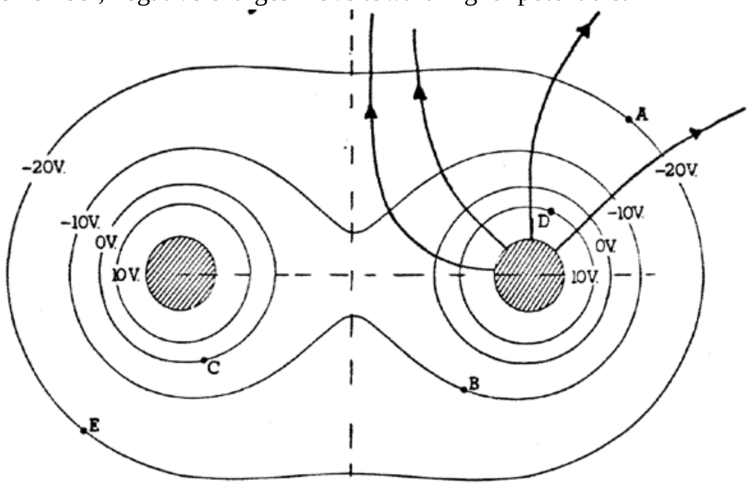
1974B5

a. Since the potential increases as you near the cylinder on the right, it must also have a positive charge. Remember, negative charges move toward higher potentials.

b.



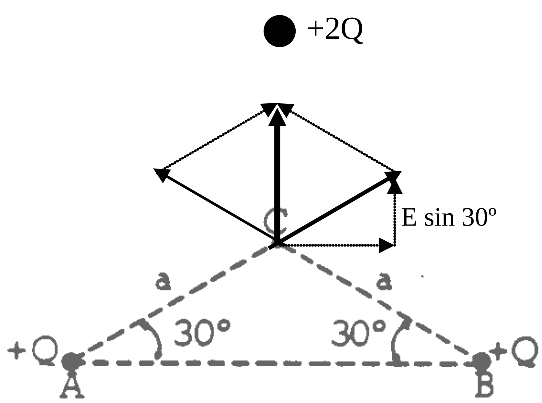
c. $V_A – V_B = (–20\text{ V}) – (–10\text{ V}) = –10\text{ V}$

d. $W_{AED} = W_{AD} = –q\Delta V = –(0.5\text{ C})(30\text{ V}) = –15\text{ J}$

1975B2

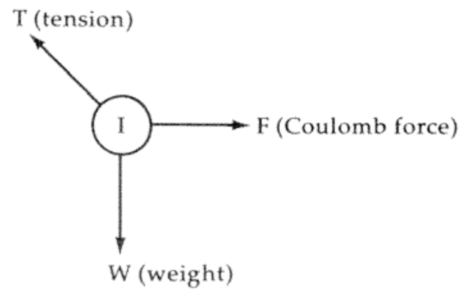
a. $V_C = kQ/a + kQ/a = 2kQ/a$; $W = –q\Delta V = – (+q)(V_\infty – V_C) = –q(0 – 2kQ/a) = 2kQq/a$

b. Looking at the diagram below, the fields due to the two point charges cancel their x components and add their y components, each of which has a value $(kQ/a^2) \sin 30^\circ = ½\ kQ/a^2$ making the net E field (shown by the arrow pointing upward) $2 \times ½\ kQ/a^2 = kQ/a^2$. For this field to be cancelled, we need a field of the same magnitude pointing downward. This means the positive charge +2Q must be placed directly above point C at a distance calculated by $k(2Q)/d^2 = kQ/a^2$ giving $d = \sqrt{2}a$



1979B7

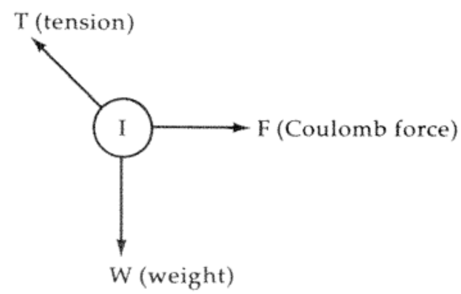
a.



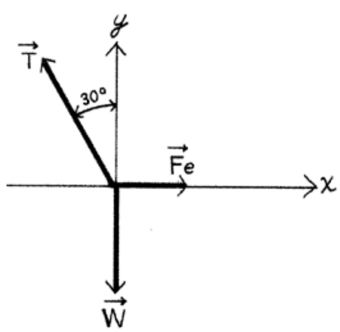
b. Resolving the tension into components we have T cos θ = W and T sin θ = F
where W = mg and $F = kq^2/r^2$ and $r = 2l \sin\theta$ giving $F = kq^2/(4l^2 \sin^2\theta)$
Dividing the two expressions we get $\tan\theta = F/mg = kq^2/(4l^2 \sin^2\theta\ mg)$
solving yields $q^2 = 4mgl^2 (\sin^2\theta)(\tan\theta)/k$

1981 B3

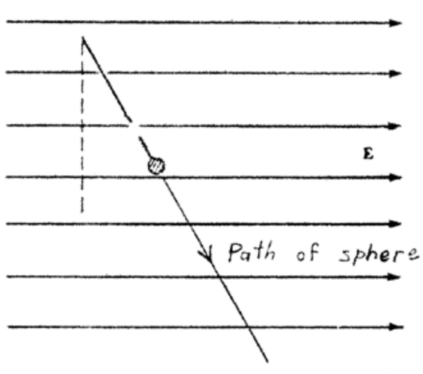
a.



b.



T cos 30º = mg so T = 0.058 N
$T \sin\theta = F_E = Eq$ gives $E = 5.8 \times 10^3$ N/C

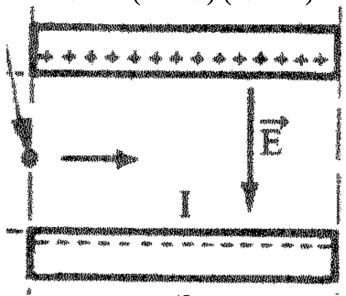


c. After the string is cut, the only forces are gravity, which acts down, and the electrical force which acts to the right. The resultant of these two forces causes a constant acceleration along the line of the string. The path is therefore down and to the right, along the direction of the string as shown above.

1985B3

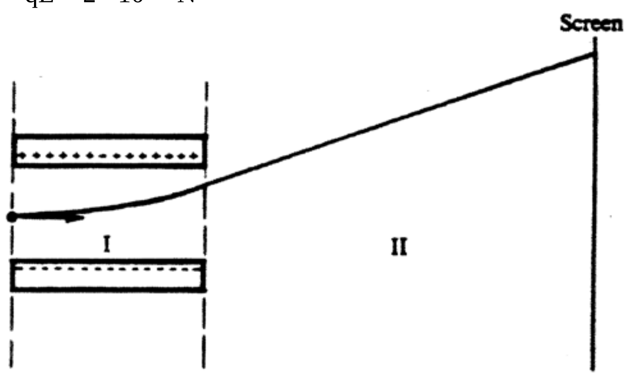
a. $K = (2 \times 10^3\ eV)(1.6 \times 10^{-19}\ J/eV) = 3.2 \times 10^{16}\ J$
   $K = ½\ mv^2$ gives $v = 2.7 \times 10^7\ m/s$

b. $E = \Delta V/d = (250\ V)/(0.02\ m) = 1.25 \times 10^4\ V/m$



c. $F = qE = 2 \times 10^{-15}\ N$

d.



Path curves parabolically toward the upper plate in region I and moves in a straight line in region II.

1987B2

a. $V = kQ/r = 9 \times 10^4\ V$

b. $W = q\Delta V$ (where V at infinity is zero) = 0.09 J

c. $F = kqQ/r^2 = 0.3\ N$

d. Between the two charges, the fields from each charge point in opposite directions, making the resultant field the difference between the magnitudes of the individual fields.
   $E = kQ/r^2$ gives $E_I = 1.2 \times 10^6$ N/C to the right and $E_{II} = 0.4 \times 10^6$ N/C to the left
   The resultant field is therefore $E = E_I - E_{II} = 8 \times 10^5$ N/C to the right

e. From conservation of momentum $m_Iv_I = m_{II}v_{II}$ and since the masses are equal we have $v_I = v_{II}$.
   Conservation of energy gives $U = K = 2(½\ mv^2) = 0.09$ J giving v = 6 m/s

---

1989B2

a. $E = kQ/r^2$ and since the field is zero $E_1 + E_2 = 0$ giving $k(Q_1/r_1{}^2 + Q_2/r_2{}^2) = 0$
   This gives the magnitude of $Q_2 = Q_1(r_2{}^2/r_1{}^2) = 2\mu C$ and since the fields must point inopposite directions from each charge at point P, Q_2 must be negative.

b. $F = kQ_1Q_2/r^2 = 3.6$ N to the right (they attract)

c. $U = kQ_1Q_2/r = -0.72$ J

d. between the charges we have a distance from Q_1 of x and from Q_2 of (0.2 m – x)
   $V = kQ_1.x + kQ_2/(0.2\ m - x) = 0$, solving for x gives x = 0.16 m

e. $W = q\Delta V$ where $\Delta V = V_\infty - V_R = 0$ so W = 0

1990B2

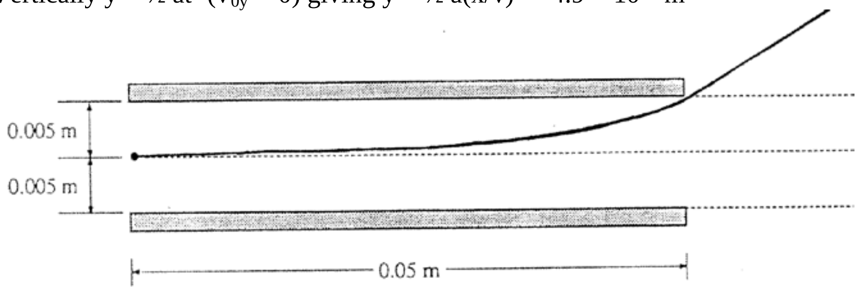
a. $E = V/d = 2 \times 10^4$ V/m

b. $F = Eq = ma$ gives $a = qE/m = 3.5 \times 10^{15}$ m/s^2

c. Horizontally: $x = vt$ giving $t = x/v$

Vertically $y = \frac{1}{2} at^2$ ($v_{0y} = 0$) giving $y = \frac{1}{2} a(x/v)^2 = 4.9 \times 10^{-3}$ m

d.

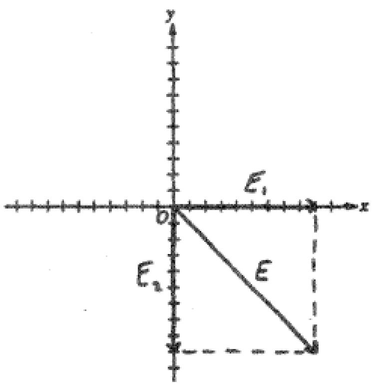


1993B2

a. i. $E = kq/r^2 = 9000$ N/C

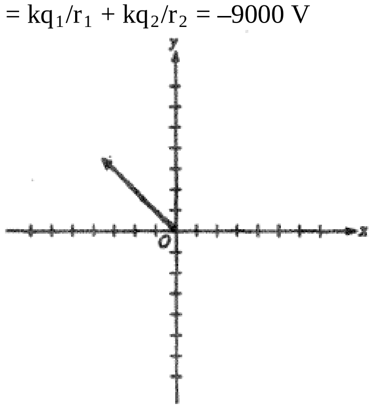
ii. $E = kq/r^2 = 9000$ N/C

iii.



b. $V = kq_1/r_1 + kq_2/r_2 = -9000$ V

c.



Since the charge is negative, the force acts opposite the direction of the net E field.

d. $W = q\Delta V = 0.036$ J

1996B6

a. $\Sigma F = 0$ gives $qE = mg$ and $q = mg/E = 3.27 \times 10^{-19}$ C
b. The drop must have a net negative charge. The electric force on a negative charge acts opposite the direction of the electric field.
c. $V = Ed = 100$ V
d. The drop moves upward. The reduced mass decreases the downward force of gravity on the drop while if the charge remains the same, the upward electric force is unchanged.

2002B5B

a. Electric field lines point away from positive charges and toward negative charges. The plate on the left is negative and the plate on the right is positive.
b. $V = Ed = 100$ V
c. $C = \varepsilon_0 A/d = 1.3 \times 10^{-10}$ F
d. $F = qE = 8 \times 10^{-16}$ N to the right (opposite the direction of the electric field)
e. The potential difference between the center and one of the plates is 50 V.
   $W = qV = \frac{1}{2}mv^2$ gives $v = 4.2 \times 10^6$ m/s

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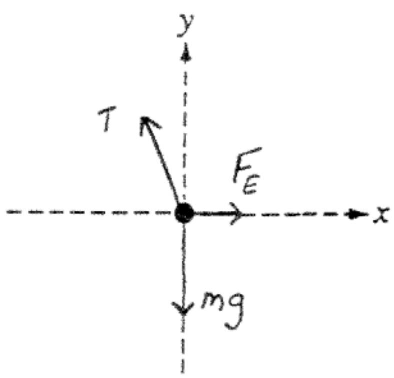
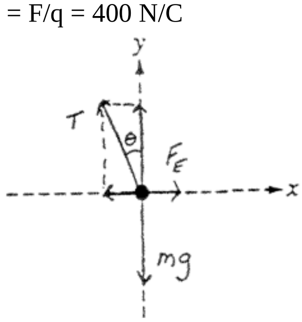
1998B2

a.



b. $E = F/q = 400$ N/C
c.



T sin θ = F_E and T cos θ = mg. Dividing gives tan θ = F/mg and θ = 18º.
From the diagram sin θ = x/(0.30 m) giving x = 0.09 m

d. i. $a_x = F/m = 3.2$ m/s^2; $a_y = 9.8$ m/s^2
   $a = \sqrt{a_x^2 + a_y^2} = 10.3$ m/s^2; tan θ = (9.8 m/s^2)/(3.2 m/s^2) = 72º below the x axis
   (or 18º to the right of the y axis, the same as the angle of the string)
   ii. The ball moves in a straight line down and to the right

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<u>1999B2</u>

a. $W = qV = ½ mv^2$ gives $V = mv^2/2q = 1.0 \times 10^4$ V

b. Electrons travel toward higher potential making the upper plate at the higher potential.

c. i. $x = v_x t$ gives $t = 6.7 \times 10^{-10}$ s

ii. $F = ma = qE$ and $E = V/d$ gives $a = qV/md$ and $y = ½ at^2$ ($v_{0y} = 0$) gives $y = qVt^2/2md = 6.5 \times 10^{-4}$ m

d. F_g is on the order of 10^{-30} N (mg) and $F_E = qE = qV/d$ is around 10^{-14} N so $F_E \gg F_g$

e. Since there is no more electric force, the path is a straight line.

<u>2001B3</u>

a. i. $V = \Sigma kQ/r = k(-Q/r + -Q/r + Q/r + Q/r) = 0$

ii. The fields from the charges on opposing corners cancels which gives E = 0

b. i. $V = \Sigma kQ/r = k(-Q/r + -Q/r + Q/r + Q/r) = 0$

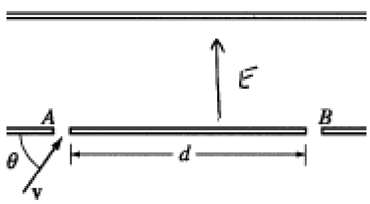
ii. The field from each individual charge points along a diagonal, with an *x*-component to the right. The vertical components cancel in pairs, and the *x*-components are equal in magnitude. Each x component being $E = kQ/r^2 \cos 45^\circ$ and the distance from a corner to the center of $r^2 = s^2/2$ gives

$E = 4E_x = 4\frac{kQ}{s^2/2}\frac{\sqrt{2}}{2} = 4\sqrt{2}kQ/s^2$

c. Arrangement 1. The force of attraction on the upper right charge is greater in arrangement 1 because the two closest charges are both positive, whereas in arrangement 2 one is positive and one is negative.

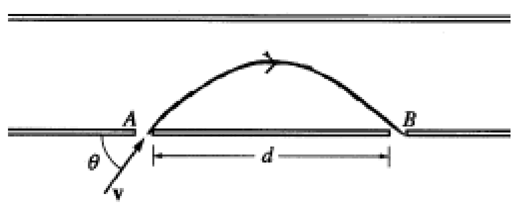
<u>2003B4B</u>

a. i.



ii.

iii.



b. $F = ma = qE$ gives $a = qE/m$

c. The acceleration is downward and at the top of the path, $v_y = v_{0y} - at = 0$ and $v_{0y} = v \sin\theta$ which gives $t_{top} = v \sin\theta/a$ or $t_{total} = 2t_{top} = 2v \sin\theta/a$ and substituting a from part b gives $t = (2mv \sin\theta)/qE$

d. $d = x_x t$ where $v_x = v \cos\theta$ giving $d = (2mv^2 \sin\theta \cos\theta)/qE$

e. The distance would be less because gravity, acting downward, will increase the electron's downward acceleration, decreasing the time spent in the field.

2005B3

a. $E = kq/r^2$ and the field from each charge points in opposite directions, with the larger field contribution pointing upward. $E_O = k(2q)/a^2 - kq/a^2 = kq/a^2$ upward (+y)

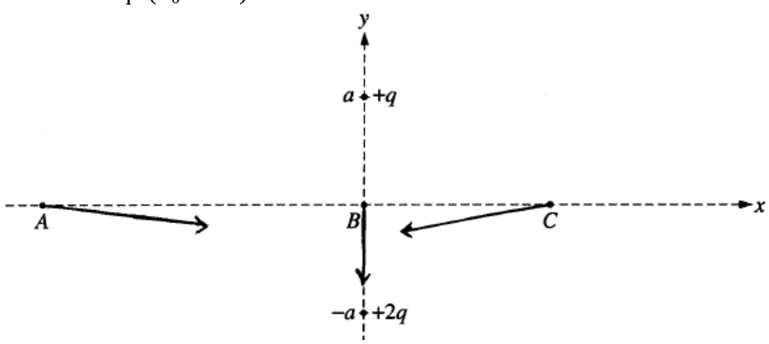
b. $V_O = \Sigma kq/r = k(2q)/a + kq/a = 3kq/a$

c. $F = kq_1q_2/r^2$ where in this case $r^2 = x_0^2 + a^2$

   i. $F = kq^2/(x_0^2 + a^2)$

   ii. $F = 2kq^2/(x_0^2 + a^2)$

d.



2005B3B

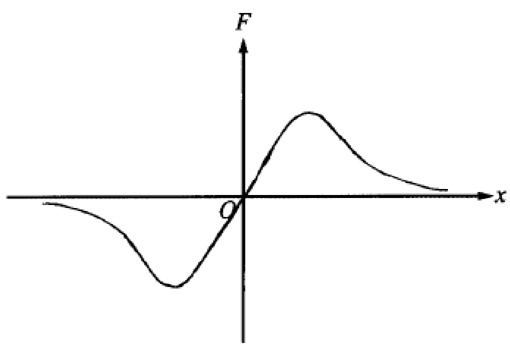
a. The distance between the charges is $r = \sqrt{a^2 + (2a)^2} = \sqrt{5}a$ The y components of the forces due to the two –2Q charges cancel so the magnitude of the net force equals the sum of the x components, where $F_x = F\cos\theta$ and $\cos\theta = 2a/r = 2/\sqrt{5}$

   Putting this all together gives $F_x = 2 \times (kQ(2Q)/r^2)\cos\theta = 8kQ^2/5\sqrt{5}a^2$ to the right (+x)

b. The contribution to the field from the –2Q charges cancel. This gives $E = kQ/(2a)^2 = kQ/4a^2$ to the right (+x)

c. $V = \Sigma kQ/r = k(-2Q)/a + k(-2Q)/a + k(-Q)/2a = -9kQ/2a$

d. At the origin the force is zero (they cancel). As the charge moves away from the origin, the force first increases as the x components grow, then decrease as the distance grows larger.



2006B3

a. Positive. The electric field due to q_1 points to the right since q_1 is negative. For the electric field to be zero at point P, the field form q_2 must point to the left, away from q_2 making q_2 positive.

b. $\mathbf{E}_1 + \mathbf{E}_2 = 0$ so setting the fields from each charge equal in magnitude gives $kq_1/d_1^2 = kq_2/d_2^2$, or $q_2 = q_1(d_2^2/d_1^2) = 4.8 \times 10^{-8}$ C

c. $F = kq_1q_2/r^2 = 1.4 \times 10^{-5}$ N to the left

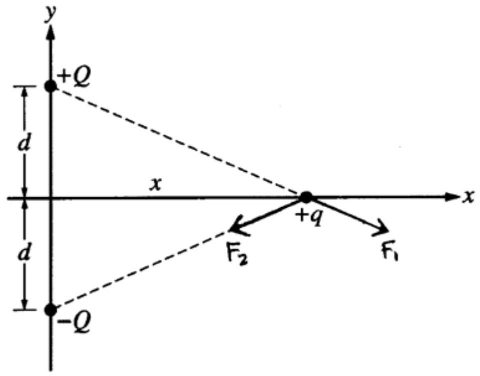
d. $V_1 + V_2 = 0 = kq_1/r_1 + kq_2/r_2$ and let $r_2 = d$ and $r_1 = (0.3\text{ m} - d)$

   solving yields d = 0.28 m to the left of q_2 which is at x = 0.20 m – 0.28 m = –0.08 m

e. $W = q\Delta V$ and since $\Delta V = 0$, $W = 0$

2006B3B

a.



b. The x components of the forces cancel so the net force is the sum of the y components, which are equal in magnitude and direction. $F_{net} = 2 \times F \cos\theta$ where θ is the angle between the y axis and the dashed line in the diagram above. $\cos\theta = d/r = d/\sqrt{x^2 + d^2}$
This gives $F_{net} = 2 \times kqQ/r^2 \times \cos\theta = 2kqQd/(x^2 + d^2)^{3/2}$

c. $E = F/q$ at the point where q_1 lies. $E = 2kQd/(x^2 + d^2)^{3/2}$

d. Since the charges Q and –Q are equidistant from the point and $V = \Sigma kQ/r$, the potential $V = 0$

e. As x gets large, the distance to the charges r and the value of x become similar, that is $\sqrt{x^2 + d^2} \approx x$.
Substituting this into the answer to b. yields $F = 2kqQd/x^3$

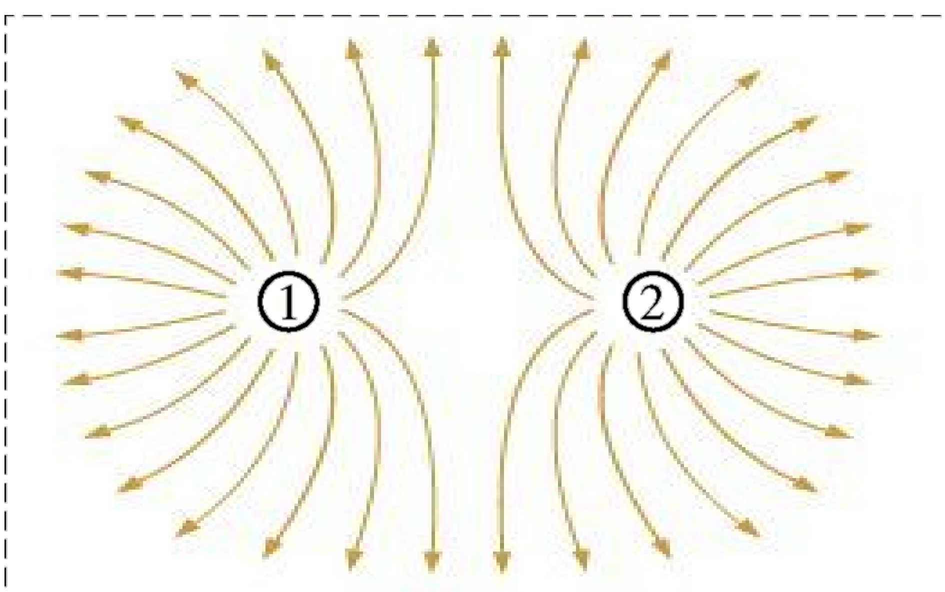
2009B2B

a. The x components of the forces due to the charges q_B cancel making the net force equal to the sum of the y components which are equal in magnitude and both point downward. The distance between q_A and either q_B is found by the Pythagorean theorem to be 0.05 m. $F_y = F \sin\theta$ where θ is the angle between the line joining q_A and q_B and the x axis, giving $\sin\theta = 3/5$.
This gives $F_{net} = 2 \times F_y = 2\,(kq_Aq_B/r^2) \times \sin\theta = 2.6 \times 10^{-7}$ N down (–y)

b. Particle A will accelerate downward, but as the particle approaches the origin, the force and the acceleration will decrease to zero at the origin. It will then pass through the origin, with a net force now pointing upward, where it will eventually slow down and reverse direction, repeating the process. The short answer is the particle will oscillate vertically about the origin.

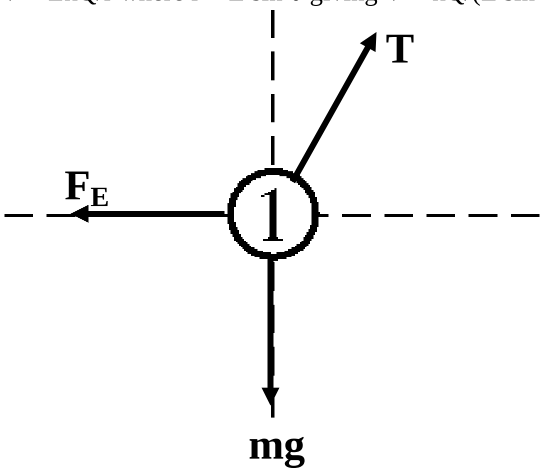
2009B2

a.



b. $V = \Sigma kQ/r$ where $r = L \sin \theta$ giving $V = kQ/(L \sin \theta) + kQ/(L \sin \theta) = 2kQ/(L \sin \theta)$

c.



d. $\Sigma F_y = 0$; $T \cos \theta = mg$
$\Sigma F_x = 0$; $T \sin \theta = F_E = kQ^2/(2L \sin \theta)^2$

1974E2

a. $E = V/d = V/b$

b. $C = \varepsilon_0 A/d = \varepsilon_0 A/b$; $Q = CV = \varepsilon_0 AV/b$

c. This arrangement acts as two capacitors in series, which each have a potential difference ½ V. Using $E = V/d$ where $d = ½(b – a)$ for each of the spaces above and below. This gives $E = V/d = (½\ V)/½(b – a) = V/(b – a)$

d. With the copper inserted, we have two capacitors in series, each with a spacing ½(b – a). The capacitance of each is then $\varepsilon_0 A/(½(b – a))$ and in series, two equal capacitors have an equivalent capacitance of ½ C makinf the total capacitance with the copper inserted $½\varepsilon_0 A/(½(b – a)) = \varepsilon_0 A/(b – a)$ making the ratio $b/(b – a)$. Notice the final capacitance is effectively a new single capacitor with an air gap of (b – a). Imagine sliding the copper slab up to touch the top plate, this is the same result. This is why adding capacitors in series decreases the capacitance as if the gap between the plates was increased.

1975E1

a. To find V along the x axis we use $V = \Sigma kq/r$ where $r = \sqrt{l^2 + x^2}$ giving $V = 2kq/\sqrt{l^2 + x^2}$ and $U_E = qV$ so as a function of x we have $U_E = 2kq^2/\sqrt{l^2 + x^2}$

b. Along the x axis, the y components of the forces cancel and the net force is then the sum of the x components of the forces. Since x = l in this case, the forces make an angle of 45º to the x axis and we have $F = 2 \times F_x = 2 \times F \times \cos 45º = 2 \times kq^2/(\sqrt{l^2 + l^2})^2 \times \cos 45º = kq^2/\sqrt{2}l^2$

c. At the origin, the potential is $V = kq/l + kq/l = 2kq/l$ and with $V_\infty = 0$ we have $W = –q\Delta V = –2kq^2/l$

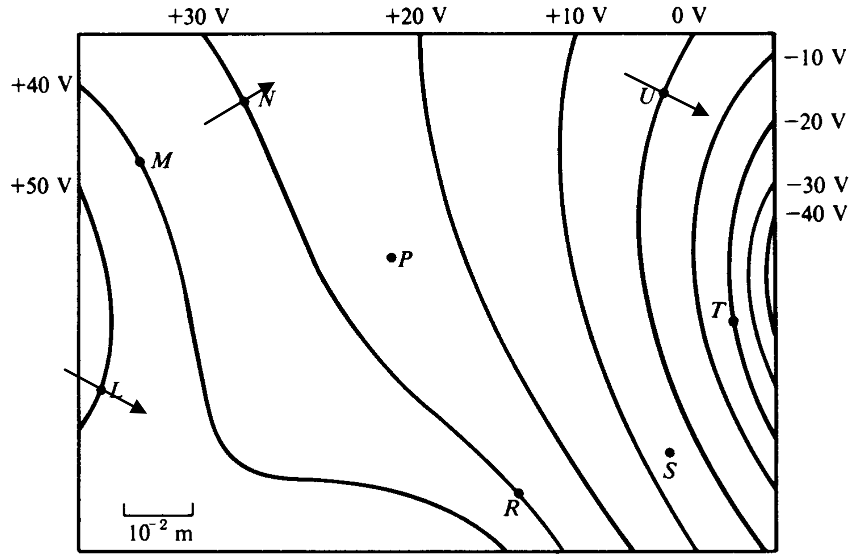
1982E1

a. $V = \Sigma kq/r = –kq/x + 2kq/\sqrt{a^2 + x^2} = 0$ which gives $1/x = 2/\sqrt{a^2 + x^2}$ cross multiplying and squaring gives $4x^2 = a^2 + x^2$ yielding $x = \pm a/\sqrt{3}$

b. $E = kq/r^2$ and by symmetry, the y components cancel. The x components of the electric field from the positive charges points to the right and has magnitude $(kq/r^2) \cos \theta$ where $\cos \theta = x/r = x/\sqrt{x^2 + a^2}$ and the x component of the electric field from the –q charge points to the left with magnitude kq/x^2 making the net field
$E = 2kqx/(x^2 + a^2)^{3/2} – kq/x^2$

1986E1

a.



The field lines point perpendicular to the equipotential lines from high to low potential.

b. The magnitude of the field is greatest at point T because the equipotential lines are closest together, meaning ΔV has the largest gradient, which is related to the strength of the electric field.

c. E = ΔV/d = (10 V)/(0.02 m) = 500 V/m

d. $V_M - V_S$ = 40 V – 5 V = 35 V

e. W = –qΔV and ΔV = – 10 V which gives W = 5 $\times 10^{-11}$ J

f. The work done is independent of the path so the answer would be the same.

1991E1

a. E = kQ/a^2 for each charge, but each vector points in the opposite direction so E = 0

b. V = kQ/a + kQ/a = 2kQ/a

c. the distance to point P from either charge is r = $\sqrt{a^2 + b^2}$ and the magnitude of E is $kQ/r^2 = kQ/(a^2 + b^2)$

The x components cancel so we have only the y components which are E sin θ where sin θ = b/$\sqrt{a^2 + b^2}$ and adding the 2 y components from the two charges gives Enet = $2kQb/(a^2 + b^2)^{3/2}$

d. The particle will be pushed back toward the origin and oscillate left and right about the origin.

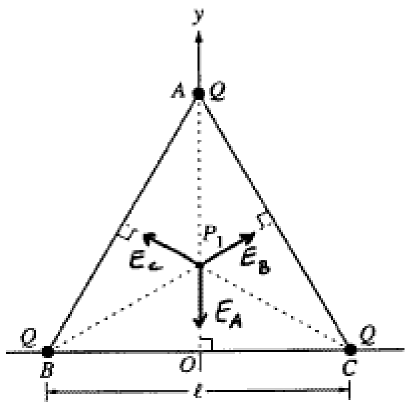
e. The particle will accelerate away from the origin.

The potential of at the center is 2kQ/a and far away $V_\infty = 0$. To find the speed when far away we use W = qΔV = K = ½ mv^2 which gives $v = 2\sqrt{\frac{kQq}{ma}}$

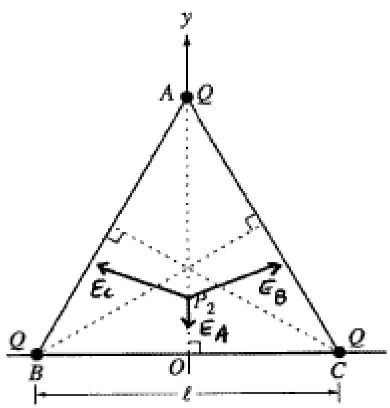
f. The particle will be pulled back toward the origin and oscillate up and down around the origin.

2000E2

a. i.



ii.



	Greater than at P_1	Less than at P_1	The same as at P_1
E_A		✓	
E_B	✓		
E_C	✓		

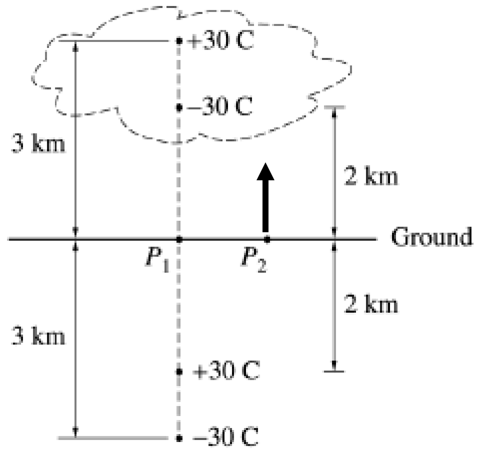
b. The x components cancel due to the symmetry about the y axis.

c. $V = \Sigma kQ/r = kQ_A/r_A + kQ_B/r_B + kQ_C/r_C$ where the terms for B and C are equal so we have $V = kQ_A/r_A + 2Q/r_B$ and using the proper geometry for the distances gives $V = k\left[\frac{Q}{\frac{\sqrt{3}l}{2} - y} + \frac{2Q}{\sqrt{\frac{l^2}{4} + y^2}}\right]$

2001E1

a. E is the vector sum of kQ/r^2. Let fields directed upward be positive and fields directed downward be negative. This gives E = k[– 30 C/(3000 m)^2 + 30 C/(2000 m)^2 + 30 C/(2000 m)^2 – 30 C/(3000 m)^2] = 75,000 N/C upward

b. i.



ii. Because it is a larger distance from the charges, the magnitude is less.

c. i. By symmetry, the potentials cancel and V = 0

ii. By symmetry, the potentials cancel and V = 0

d. V = ΣkQ/r = k[30 C/(2000 m) – 30 C/(1000 m) + 30 C/(3000 m) – 30 C/(4000 m)] = –1.12 × 10^8 V

e. U = kq_1q_2/r for *each pair* of charges
= k[(30)(–30)/1000 + (30)(30)/5000 + (30)(–30)/6000 + –30(30)/4000 + –30(–30)/5000 + 30(–30)/1000] = –1.6 × 10^{10} J

2005E1

a. i. The magnitude of the field is greatest at point C because this is where the field lines are closest together.

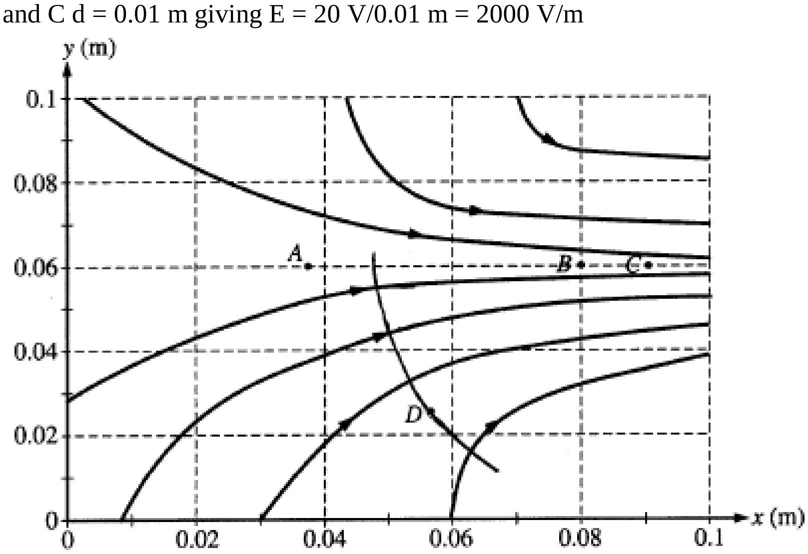
ii. The potential is greatest at point A. Electric field lines point from high to low potential.

b. i. The electron moves to the left, against the field lines. As the field gets weaker the electron's acceleration to the left decreases in magnitude, all the while gaining speed to the left.

ii. W = qΔV = ½ mv^2 gives v = 1.9 × 10^6 m/s

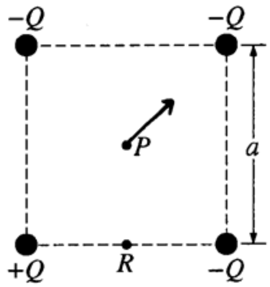
c. If we assume the field is nearly uniform between B and C we can use E = ΔV/d where the distance between B and C d = 0.01 m giving E = 20 V/0.01 m = 2000 V/m

d.



2006E1

a.



b. i. The fields at point *P* due to the upper left and lower right negative charges are equal in magnitude and opposite in direction so they sum to zero. The fields at point *P* due to the other two charges are equal in magnitude and in the same direction so they add.
Using $r^2 = a^2/2$ we have $E = 2 \times kQ/r^2 = 4kQ/a^2$

ii. $V = \Sigma kQ/r = k(-Q - Q - Q + Q)/r = -2kQ/r$ with $r = a/\sqrt{2}$ giving $V = -2\sqrt{2}kQ/a$

c. Negative. The field is directed generally from *R* to *P* and the charge moves in the opposite direction. Thus, the field does negative work on the charge.

d. i. Replace the top right negative charge with a positive charge OR replace the bottom left positive charge with a negative charge. The vector fields/forces all cancel from oppositely located same charge pairs.

ii. Replace the top left negative charge with a positive charge OR replace the bottom right negative charge with a positive charge. The scalar potentials all cancel from equidistant located opposite charge pairs. The field vectors in these cases will not cancel.

2009E2

a. $W = qV_0 = \frac{1}{2} mv^2$ giving $v = \sqrt{\frac{2eV_0}{m}}$

b. i. The time to travel horizontally a distance y_0 is found from $v = d/t$ giving $t = d/v = y_0/\sqrt{\frac{2eV_0}{m}}$

The downward acceleration of the electron is found from $F = qE = ma$ giving $a = eE/m$ and using $y = \frac{1}{2} at^2$ and substituting the values found earlier we have $y = y_0 = \frac{1}{2} (eE/m)(y_0{}^2)/(2eV_0/m)$ which yields $E = 4V_0/y_0$

ii. For the electron to accelerate downward requires the electric field to point upward, toward the top of the page since negative charges experience forces opposite electric field lines.

c. $\Delta V = ED = (4D/y_0)V_0$