CHAPTER 17

1. We find the work done by an external agent from the work-energy principle:
   W = ÆKE + ÆPE = 0 + $q(V_b - V_a)$
   = $(-8.6 \times 10^{-6}$ C)(+ 75 V – 0)= -6.5×10^{-4} J (done by the field).

2. We find the work done by an external agent from the work-energy principle:
   W = ÆKE + ÆPE = 0 + $q(V_b - V_a)$
   = $(1.60 \times 10^{-19}$ C)[(– 50 V) – (+ 100 V)] = -2.40×10^{-17} J (done by the field);
   $W = q(V_b - V_a)$
   = (+ 1 e)[(– 50 V) – (+ 100 V)] = – 150 eV.

3. Because the total energy of the electron is conserved, we have
   ÆKE + ÆPE = 0, or
   ÆKE = $-q(V_B - V_A)$ = – $(-1.60 \times 10^{-19}$ C)(21,000 V) = 3.4×10^{-15} J;
   ÆKE = – (– 1 e)(21,000 V) = 21 keV.

4. Because the total energy of the electron is conserved, we have
   ÆKE + ÆPE = 0;
   ÆKE + $q(V_B - V_A) = 0$;
   3.45×10^{-15} J + $(-1.60 \times 10^{-19}$ C)$(V_B - V_A)$; which gives $V_B - V_A$ = 2.16×10^{3} V.
   Plate *B* is at the higher potential.

5. For the uniform electric field between two large, parallel plates, we have
   E = ÆV/d = (220 V)/(5.2×10^{-3} m) = 4.2×10^{4} V/m.

6. For the uniform electric field between two large, parallel plates, we have
   E = ÆV/d;
   640 V/m = ÆV/(11.0×10^{-3} m), which gives ÆV = 7.04 V.

7. Because the total energy of the helium nucleus is conserved, we have
   ÆKE + ÆPE = 0;
   ÆKE + $q(V_B - V_A) = 0$;
   65.0 keV + (+ 2e)$(V_B - V_A)$; which gives $V_B - V_A$ = – 32.5 kV.

8. For the uniform electric field between two large, parallel plates, we have
   E = ÆV/d;
   3×10^{6} V/m = (100 V)/d, which gives d = 3×10^{-5} m.

9. We use the work-energy principle:
   W = ÆKE + ÆPE = ÆKE + $q(V_b - V_a)$;
   25.0×10^{-4} J = 4.82×10^{-4} J + $(-7.50 \times 10^{-6}$ C)$(V_b - V_a)$, which gives $V_b - V_a$ = – 269V, or
   $V_a - V_b$ = 269 V.

10. The data given are the kinetic energies, so we find the speed from

(*a*) $\text{KE}_a = !mv_a^2$;

$(750\text{ eV})(1.60 \times 10^{-19}\text{ J/eV}) = !(9.11 \times 10^{-31}\text{ kg})v_a^2$, which gives $v_a =$ $1.62 \times 10^7\text{ m/s}$.

(*b*) $\text{KE}_b = !mv_b^2$;

$(3.5 \times 10^3\text{ eV})(1.60 \times 10^{-19}\text{ J/eV}) = !(9.11 \times 10^{-31}\text{ kg})v_b^2$, which gives $v_b =$ $3.5 \times 10^7\text{ m/s}$.

11. We find the speed from

$\text{KE} = !mv^2$;

$(28.0 \times 10^6\text{ eV})(1.60 \times 10^{-19}\text{ J/eV}) = !(1.67 \times 10^{-27}\text{ kg})v^2$, which gives $v =$ $7.32 \times 10^7\text{ m/s}$.

12. We find the speed from

$\text{KE} = !mv^2$;

$(5.53 \times 10^6\text{ eV})(1.60 \times 10^{-19}\text{ J/eV}) = !(6.64 \times 10^{-27}\text{ kg})v^2$, which gives $v =$ $1.63 \times 10^7\text{ m/s}$.

13. We find the electric potential of the point charge from

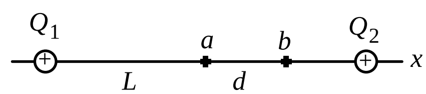
$V = kq/r = (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(4.00 \times 10^{-6}\text{ C})/(15.0 \times 10^{-2}\text{ m}) =$ $2.40 \times 10^5\text{ V}$.

14. We find the charge from

$V = kQ/r$;

$125\text{ V} = (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)Q/(15 \times 10^{-2}\text{ m})$, which gives $Q = 2.1 \times 10^{-9}\text{ C} =$ 2.1 nC.

15. We find the electric potentials of the stationary charges at the initial and final points:



$V_a = k[(Q_1/r_{1a}) + (Q_2/r_{2a})]$

$= (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)\{[(30 \times 10^{-6}\text{ C})/(0.16\text{ m})] + [(30 \times 10^{-6}\text{ C})/(0.16\text{ m})]\} = 3.38 \times 10^6\text{ V}.$

$V_b = k[(Q_1/r_{1b}) + (Q_2/r_{2b})]$

$= (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)\{[(30 \times 10^{-6}\text{ C})/(0.26\text{ m})] + [(30 \times 10^{-6}\text{ C})/(0.06\text{ m})]\} = 5.54 \times 10^6\text{ V}.$

Because there is no change in kinetic energy, we have

$W_{a \to b} = ÆK + ÆU = 0 + q(V_b - V_a)$

$= (0.50 \times 10^{-6}\text{ C})(5.54 \times 10^6\text{ V} - 3.38 \times 10^6\text{ V}) =$ $+1.08\text{ J}$.

16. (*a*) We find the electric potential of the proton from

$V = kq/r = (9.0 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(1.60 \times 10^{-19}\text{ C})/(2.5 \times 10^{-15}\text{ m}) =$ $5.8 \times 10^5\text{ V}$.

(*b*) We find the electric potential energy of the system by considering one of the charges to be at the potential created by the other charge:

$\text{PE} = qV = (1.60 \times 10^{-19}\text{ C})(5.76 \times 10^5\text{ V}) =$ $9.2 \times 10^{-14}\text{ J}$ $= 0.58\text{ MeV}$.

17. When the proton is accelerated by a potential, it acquires a kinetic energy:

 $\text{KE} = Q_p V_{\text{accel}}$.

 If it is far from the silicon nucleus, its potential is zero. It will slow as it approaches the positive charge of the nucleus, because the potential produced by the silicon nucleus is increasing. At the proton’s closest point the kinetic energy will be zero. We find the required accelerating potential from

 ÆKE + ÆPE = 0;

 $0 - \text{KE} + Q_p(V_{\text{Si}} - 0) = 0$, or

 $Q_p V_{\text{accel}} = Q_p k Q_{\text{Si}}/(R_p + R_{\text{Si}})$;

 $V_{\text{accel}} = (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(14)(1.60 \times 10^{-19}\ \text{C})/(1.2 \times 10^{-15}\ \text{m} + 3.6 \times 10^{-15}\ \text{m})$

 $= 4.2 \times 10^6\ \text{V} =$ 4.2 MV.

18. We find the potential energy of the system of charges by adding the work required to bring the three electrons in from infinity successively. Because there is no potential before the electrons are brought in, for the first electron we have

 $W_1 = (-e)V_0 = 0$.

 When we bring in the second electron, there will be a potential from the first:

 $W_2 = (-e)V_1 = (-e)k(-e)/r_{12} = ke^2/d$.

 When we bring in the third electron, there will be a potential from the first two:

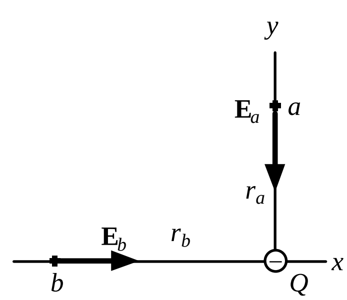
 $W_3 = (-e)V_2 = (-e)\{[k(-e)/r_{13}] + [k(-e)/r_{23}]\} = 2ke^2/d$.

 The total work required is

 $W = W_1 + W_2 + W_3 = (ke^2/d) + (2ke^2/d) = 3ke^2/d$

 $= 3(9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.60 \times 10^{-19}\ \text{C})^2/(1.0 \times 10^{-10}\ \text{m}) =$ 6.9×10^{-18} J $= 43$ eV.

19. (*a*) We find the electric potentials at the two points:

 $V_a = kQ/r_a$

 $= (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(-3.8 \times 10^{-6}\ \text{C})/(0.70\ \text{m})$

 $= -4.89 \times 10^4\ \text{V}$.

 $V_b = kQ/r_b$

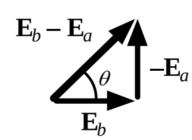
 $= (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(-3.8 \times 10^{-6}\ \text{C})/(0.80\ \text{m})$

 $= -4.28 \times 10^4\ \text{V}$.

 Thus the difference is

 $V_{ba} = V_b - V_a = -4.28 \times 10^4\ \text{V} - (-4.89 \times 10^4\ \text{V}) =$ $+6.1 \times 10^3$ V.

 (*b*) We find the electric fields at the two points:

 $E_a = kQ/r_a^2$

 $= (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(-3.8 \times 10^{-6}\ \text{C})/(0.70\ \text{m})^2$

 $= 6.98 \times 10^4$ N/C toward Q (down).

 $E_b = kQ/r_b^2$

 $= (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(-3.8 \times 10^{-6}\ \text{C})/(0.80\ \text{m})^2$

 $= 5.34 \times 10^4$ N/C toward Q (right).

 As shown on the vector diagram, we find the direction of $\mathbf{E}_b - \mathbf{E}_a$ from

 $\tan\theta = E_a/E_b = (6.98 \times 10^4\ \text{N/C})/(5.34 \times 10^4\ \text{N/C}) = 1.307$, or $\theta =$ 53° N of E.

 We find the magnitude from

 $|\mathbf{E}_b - \mathbf{E}_a| = E_b/\cos\theta = (5.34 \times 10^4\ \text{N/C})/\cos 53° =$ 8.8×10^4 N/C.

20. When the electron is far away, the potential from the fixed charge is zero.
Because energy is conserved, we have

$\Delta KE + \Delta PE = 0;$

$\frac{1}{2}mv^2 - 0 + (-e)(0 - V) = 0,$ or

$\frac{1}{2}mv^2 = e(kQ/r)$

$\frac{1}{2}(9.11 \times 10^{-31}\ \text{kg})v^2 = (1.60 \times 10^{-19}\ \text{C})(9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2)(-0.125 \times 10^{-6}\ \text{C})/(0.725\ \text{m}),$

which gives $v =$ 2.33×10^7 m/s.

21. We find the electric potential energy of the system by considering one of the charges to be at the potential created by the other charge. This will be zero when they are far away. Because the masses are equal, the speeds will be equal. From energy conservation we have

$\Delta KE + \Delta PE = 0;$

$\frac{1}{2}mv^2 + \frac{1}{2}mv^2 - 0 + Q(0 - V) = 0,$ or

$2(\frac{1}{2}mv^2) = mv^2 = Q(kQ/r) = kQ^2/r;$

$(1.0 \times 10^{-6}\ \text{kg})v^2 = (9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2)(7.5 \times 10^{-6}\ \text{C})^2/(0.055\ \text{m}),$

which gives $v =$ 3.0×10^3 m/s.

22. (*a*) We find the electric potential of the proton from

$V = ke/r = (9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2)(1.60 \times 10^{-19}\ \text{C})/(0.53 \times 10^{-10}\ \text{m}) =$ 27.2 V.

(*b*) For the electron orbiting the nucleus, the attractive Coulomb force provides the centripetal acceleration:

$ke^2/r^2 = mv^2/r$, which gives $KE = \frac{1}{2}mv^2 = \frac{1}{2}ke^2/r = \frac{1}{2}eV = \frac{1}{2}(1\ \text{e})(27.2\ \text{V}) =$ 13.6 eV.

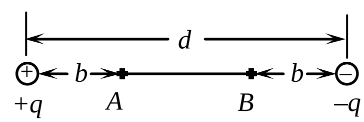
(*c*) For the total energy we have

$E = KE + PE = (\frac{1}{2}ke^2/r) + (-e)(ke/r) = -\frac{1}{2}ke^2/r =$ – 13.6 eV.

(*d*) Because the final energy of the electron is zero, for the ionization energy we have

$E_{\text{ionization}} = -E =$ 13.6 eV $(2.2 \times 10^{-18}\ \text{J})$.

23. We find the electric potentials from the charges at the two points:



$V_A = k\{(+q/b) + [-q/(d - b)]\}$

$= kq\{(1/b) - [1/(d - b)]\} = kq(d - 2b)/b(d - b).$

$V_B = k\{[+q/(d - b)] + (-q/b)\}$

$= kq\{[1/(d - b)] - (1/b)\} = kq(2b - d)/b(d - b).$

Thus we have

$V_{BA} = V_B - V_A = [kq(2b - d)/b(d - b)] - [kq(d - 2b)/b(d - b)] =$ $2kq(2b - d)/b(d - b)$.

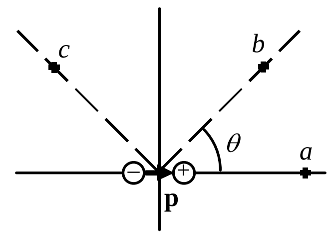
Note that, as expected, $V_{BA} = 0$ when $b = \frac{1}{2}d$.

24. (*a*) We find the dipole moment from

$p = eL = (1.60 \times 10^{-19}\ \text{C})(0.53 \times 10^{-10}\ \text{m}) =$ 8.5×10^{-30} C·m.

(*b*) The dipole moment will point from the electron toward the proton. As the electron revolves about the proton, the dipole moment will spend equal times pointing in any direction. Thus the average over time will be zero.

25. With the dipole pointing along the axis, the potential at a point a distance r from the dipole which makes an angle θ with the axis is



$V = (kp \cos \theta)/r^2$
$= (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(4.8 \times 10^{-30}\ \text{C}\cdot\text{m})(\cos \theta)/(1.1 \times 10^{-9}\ \text{m})^2$
$= (0.0357\ \text{V}) \cos \theta.$

(*a*) Along the axis, $\theta = 0$, so we have
$V = (kp \cos \theta)/r^2$
$= (0.0357\ \text{V}) \cos 0° =$ 0.036 V.

(*b*) Above the axis near the positive charge, $\theta = 45°$, so we have
$V = (kp \cos \theta)/r^2$
$= (0.0357\ \text{V}) \cos 45° =$ 0.025 V.

(*c*) Above the axis near the negative charge, $\theta = 135°$, so we have
$V = (kp \cos \theta)/r^2$
$= (0.0357\ \text{V}) \cos 135° =$ – 0.025 V.

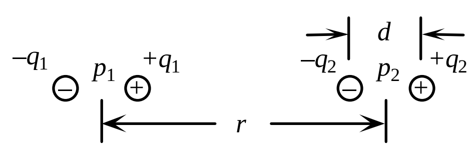
26. (*a*) With the distance measured from the center of the dipole, we find the potential from each charge:
$V_O = kQ_O/r_O$
$= (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(-\ 6.6 \times 10^{-20}\ \text{C})/(9.0 \times 10^{-10}\ \text{m} - 0.6 \times 10^{-10}\ \text{m})$
$= -\ 0.707\ \text{V}.$
$V_C = kQ_C/r_C$
$= (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(+\ 6.6 \times 10^{-20}\ \text{C})/(9.0 \times 10^{-10}\ \text{m} + 0.6 \times 10^{-10}\ \text{m})$
$= +\ 0.619\ \text{V}.$

Thus the total potential is
$V = V_O + V_C = -\ 0.707\ \text{V} + 0.619\ \text{V} =$ – 0.088 V.

(*b*) The percent error introduced by the dipole approximation is
% error = $(100)(0.089\ \text{V} - 0.088\ \text{V})/(0.088\ \text{V}) =$ 1%.

27. Because $p_1 = p_2$, from the vector addition we have
$p = 2p_1 \cos (!\theta) = 2qL \cos (!\theta)$;
$6.1 \times 10^{-30}\ \text{C}\cdot\text{m} = 2q(0.96 \times 10^{-10}\ \text{m}) \cos [!(104°)]$, which gives $q =$ 5.2×10^{-20} C.

28. We find the potential energy of the system by considering each of the charges of the dipole on the right to be in the potential created by the other dipole. The potential of the dipole on the left along its axis is



$V_1 = (kp_1 \cos \theta)/r^2 = kp_1/r^2.$

If r is the distance between centers of the dipoles, the potential energy is
$\text{PE} = (q_2)[kp_1/(r + !d)^2] + (-\ q_2)[kp_1/(r - !d)^2]$
$= q_2kp_1\{[1/(r + !d)^2] - [1/(r - !d)^2]\} = (q_2kp_1/r^2)\big(\{1/[1 + (d/2r)]^2\} - \{1/[1 - (d/2r)]^2\}\big).$

Because $d \ll r$, we can use the approximation $1/(1 \pm x)^2 \approx 1 — 2x$, when $x \ll 1$:
$\text{PE} \approx (q_2kp_1/r^2)\{[1 - (d/r)] - [1 + (d/r)]\} = -\ 2q_2dkp_1/r^3 = -\ 2kp_1p_2/r^3.$

29. Because the field is uniform, the magnitudes of the forces on the charges of the dipole will be equal:

$F_+ = F_- = QE.$

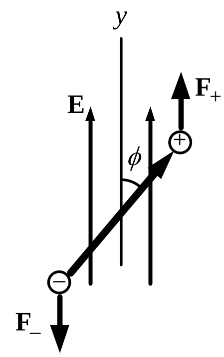
If the separation of the charges is ¬, the dipole moment will be $p = Q$¬.

If we choose the center of the dipole for the axis of rotation, both forces create a CCW torque with a net torque of

$\tau = F_+(!¬) \sin \phi + F_-(!¬) \sin \phi = 2QE(!¬) \sin \phi = pE \sin \phi.$

Because the forces are in opposite directions, the net force is zero.

If the field is nonuniform, there would be a torque produced by the average field. The magnitudes of the forces would not be the same, so there would be a resultant force that would cause a translation of the dipole.



30. From $Q = CV$, we have

$2500\ \mu C = C(950\ V)$, which gives $C =$ 2.6 μF.

31. From $Q = CV$, we have

$95\ pC = C(120\ V)$, which gives $C =$ 0.79 pF.

32. From $Q = CV$, we have

$16.5 \times 10^{-8}\ C = (7500 \times 10^{-12}\ F)V$, which gives $V =$ 22.0 V.

33. The final potential on the capacitor will be the voltage of the battery. Positive charge will move from one plate to the other, so the charge that flows through the battery is

$Q = CV = (9.00\ \mu F)(12.0\ V) =$ 108 μC.

34. For a parallel-plate capacitor, we find the area from

$C = Å_0 A/d;$

$0.20\ F = (8.85 \times 10^{-12}\ C^2/N \cdot m^2)A/(2.2 \times 10^{-3}\ m)$, which gives $A =$ $5.0 \times 10^7\ m^2$.

If the area were a square, it would be ≈ 7 km on a side.

35. We find the capacitance from

$C = KÅ_0 A/d = KÅ_0 ¹ r^2/d$

$= (7)(8.85 \times 10^{-12}\ C^2/N \cdot m^2)¹(0.050\ m)^2/(3.2 \times 10^{-3}\ m) =$ 1.5×10^{-10} F.

36. From $Q = CV$, we see that

$ÆQ = C\ ÆV;$

$15\ \mu C = C(121\ V - 97\ V)$, which gives $C =$ 0.63 μF.

37. The uniform electric field between the plates is related to the potential difference across the plates:

$E = V/d.$

For a parallel-plate capacitor, we have

$Q = CV = (Å_0 A/d)(Ed) = Å_0 AE$

$= (8.85 \times 10^{-12}\ C^2/N \cdot m^2)(35.0 \times 10^{-4}\ m^2)(8.50 \times 10^5\ V/m)$

$= 2.63 \times 10^{-8}$ C = 26.3 nC.

38. The uniform electric field between the plates is related to the potential difference across the plates:

    $E = V/d$.

    For a parallel-plate capacitor, we have

    $Q = CV = (\text{Å}_0 A/d)(Ed) = \text{Å}_0 AE$;

    $4.2 \times 10^{-6}\ \text{C} = (8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2)A(2.0 \times 10^3\ \text{V/mm})(10^3\ \text{mm/m})$,

    which gives $A =$ $0.24\ \text{m}^2$.

39. We find the potential difference across the plates from

    $Q = CV$;

    $72\ \mu\text{C} = (0.80\ \mu\text{F})V$, which gives $V = 90\ \text{V}$.

    We find the uniform electric field between the plates from

    $E = V/d = (90\ \text{V})/(2.0 \times 10^{-3}\ \text{m}) =$ $4.5 \times 10^4\ \text{V/m}$.

40. The uniform electric field between the plates is related to the potential difference across the plates:

    $E = V/d$.

    For a parallel-plate capacitor, we have

    $Q = CV = CEd$;

    $0.775 \times 10^{-6}\ \text{C} = C(9.21 \times 10^4\ \text{V/m})(1.95 \times 10^{-3}\ \text{m})$, which gives $C =$ $4.32 \times 10^{-9}\ \text{F}$.

    We find the area of the plates from

    $C = K\text{Å}_0 A/d$;

    $4.32 \times 10^{-9}\ \text{F} = (3.75)(8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2)A/(1.95 \times 10^{-3}\ \text{m})$, which gives $A =$ $0.254\ \text{m}^2$.

41. We find the initial charge on the 7.7-μF capacitor when it is connected to the battery:

    $Q = C_1 V = (7.7\ \mu\text{F})(125\ \text{V}) = 962.5\ \mu\text{C}$.

    When C_1 is disconnected from the battery and then connected to C_2, some charge will flow from C_1 to C_2. The flow will stop when the voltage across the two capacitors is the same:

    $V_1 = V_2 = 15\ \text{V}$.

    Because charge is conserved, we have

    $Q = Q_1 + Q_2$.

    We find the charge remaining on C_1 from

    $Q_1 = C_1 V_1 = (7.7\ \mu\text{F})(15\ \text{V}) = 115.5\ \mu\text{C}$.

    The charge on C_2 is

    $Q_2 = Q - Q_1 = 962.5\ \mu\text{C} - 115.5\ \mu\text{C} = 847\ \mu\text{C}$.

    We find the value of C_2 from

    $Q_2 = C_2 V_2$;

    $847\ \mu\text{C} = C_2(15\ \text{V})$, which gives $C_2 =$ $56\ \mu\text{F}$.

42. We find the initial charges on the capacitors:

$Q_1 = C_1V_1 = (2.50\ \mu\text{F})(1000\ \text{V}) = 2500\ \mu\text{C};$

$Q_2 = C_2V_2 = (6.80\ \mu\text{F})(650\ \text{V}) = 4420\ \mu\text{C}.$

When the capacitors are connected, some charge will flow from C_2 to C_1 until the potential difference across the two capacitors is the same:

$V_1' = V_2' = V.$

Because charge is conserved, we have

$Q = Q_1' + Q_2' = Q_1 + Q_2 = 2500\ \mu\text{C} + 4420\ \mu\text{C} = 6920\ \mu\text{C}.$

For the two capacitors we have

$Q_1' = C_1V$, and $Q_2' = C_2V$.

When we add these, we get

$Q_1' + Q_2' = Q = (C_1 + C_2)V;$

$6920\ \mu\text{C} = (2.50\ \mu\text{F} + 6.80\ \mu\text{F})V$, which gives $V =$ 744 V.

The charge on C_1 is

$Q_1' = C_1V = (2.50\ \mu\text{F})(744\ \text{V}) = 1.86 \times 10^3\ \mu\text{C} =$ 1.86×10^{-3} C.

The charge on C_2 is

$Q_2' = C_2V = (6.80\ \mu\text{F})(744\ \text{V}) = 5.06 \times 10^3\ \mu\text{C} =$ 5.06×10^{-3} C.

43. The energy stored in the capacitor is

$U = !CV^2 = !(7200 \times 10^{-12}\ \text{F})(550\ \text{V})^2 =$ 1.09×10^{-3} J.

44. We find the capacitance from

$U = !CV^2;$

$200\ \text{J} = !C(6000\ \text{V})^2$, which gives $C = 1.1 \times 10^{-5}\ \text{F} =$ 11 μF.

45. (*a*) The radius of the pie plate is

$r = !(9.0\ \text{in})(2.54 \times 10^{-2}\ \text{m/in}) = 0.114\ \text{m}.$

If we assume that it approximates a parallel-plate capacitor, we have

$C = \text{Å}_0A/d = \text{Å}_0{}^1r^2/d$

$= (8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2)^1(0.114\ \text{m})^2/(0.10\ \text{m}) = 3.6 \times 10^{-12}\ \text{F} =$ 3.6 pF.

(*b*) We find the charge on each plate from

$Q = CV = (3.6\ \text{pF})(9.0\ \text{V}) =$ 32 pC.

(*c*) We assume that the electric field is uniform, so we have

$E = V/d = (9.0\ \text{V})/(0.10\ \text{m}) =$ 90 V/m.

(*d*) The work done by the battery is the energy stored in the capacitor:

$W = U = !CV^2 = !(3.6 \times 10^{-12}\ \text{F})(9.0\ \text{V})^2 =$ 1.5×10^{-10} J.

(*e*) Because the battery is still connected, the electric field will not change. Insertion of the dielectric will change capacitance, charge, and work done by the battery.

46. From $C = \text{Å}_0A/d$, we see that separating the plates will change C. For the stored energy we have

$U = !CV^2 = !Q^2/C.$

Because the charge is constant, for the two conditions we have

$U_2/U_1 = C_1/C_2 = d_2/d_1 =$ 2.

47. (*a*) For the stored energy we have $U = !CV^2$. Because the capacitance does not change, we have
$U_2/U_1 = (V_2/V_1)^2 = (2)^2 =$ 4×.
(*b*) For the stored energy we have $U = !CV^2 = !Q^2/C$. The capacitance does not change, so we have
$U_2/U_1 = (Q_2/Q_1)^2 = (2)^2 =$ 4×.
(*c*) Because the battery is still connected, the potential difference will not change.
From $C = Å_0A/d$, we see that separating the plates will change C.
For the stored energy we have $U = !CV^2$, so we get
$U_2/U_1 = C_2/C_1 = (2)^2 = d_1/d_2 =$!×.

48. Because the capacitor is isolated, the charge will not change. The initial stored energy is
$U_1 = !C_1V_1^2 = !Q^2/C_1$, with $C_1 = Å_0A/d_1$.
The changes will change the capacitance:
$C_2 = KÅ_0A/d_2$.
For the ratio of stored energies, we have
$U_2/U_1 = C_1/C_2 = (Å_0A/d_1)/(KÅ_0A/d_2) = d_2/Kd_1 = !/K =$ $1/2K$.
The stored energy decreases from two factors. Because the plates attract each other, when the separation is halved, work is done by the field, so the energy decreases. When the dielectric is inserted, the induced charges on the dielectric are attracted to the plates; again work is done by the field and the energy decreases.
The uniform electric field between the plates is related to the potential difference across the plates:
$E = V/d$.
For a parallel-plate capacitor, we have
$Q = C_1V_1 = C_1E_1d_1 = C_2E_2d_2$, or
$E_2/E_1 = C_1d_1/C_2d_2 = Å_0A/KÅ_0A =$ $1/K$.

49. (*a*) Because there is no stored energy on the uncharged 4.00-μF capacitor, the total stored energy is
$U_a = !C_1V_0^2 = !(2.70 \times 10^{-6}\ \text{F})(45.0\ \text{V})^2 =$ 2.73×10^{-3} J.
(*b*) We find the initial charge on the 2.70-μF capacitor when it is connected to the battery;
$Q = C_1V_0 = (2.70\ \mu\text{F})(45.0\ \text{V}) = 121.5\ \mu\text{C}$.
When the capacitors are connected, some charge will flow from C_1 to C_2 until the potential difference across the two capacitors is the same:
$V_1 = V_2 = V$.
Because charge is conserved, we have
$Q = Q_1 + Q_2 = 121.5\ \mu\text{C}$.
For the two capacitors we have
$Q_1 = C_1V$, and $Q_2 = C_2V$.
When we form the ratio, we get
$Q_2/Q_1 = (121.5\ \mu\text{C} - Q_1)/Q_1 = C_2/C_1 = (4.00\ \mu\text{F})/(2.70\ \mu\text{F})$, which gives $Q_1 = 49.0\ \mu\text{C}$.
We find V from
$Q_1 = C_1V$;
$49.0\ \mu\text{C} = (2.70\ \mu\text{F})V$, which gives $V = 18.1$ V.
For the stored energy we have
$U_b = !C_1V^2 + !C_2V^2 = !(C_1 + C_2)V^2 = ![(2.70 + 4.00) \times 10^{-6}\ \text{F}](18.1\ \text{V})^2 =$ 1.10×10^{-3} J.
(*c*) The change in stored energy is
$ÆU = U_b - U_a = 1.10 \times 10^{-3}\ \text{J} - 2.73 \times 10^{-3}\ \text{J} =$ -1.63×10^{-3} J.
(*d*) The stored potential energy is not conserved. During the flow of charge before the final steady state, some of the stored energy is dissipated as thermal and radiant energy.

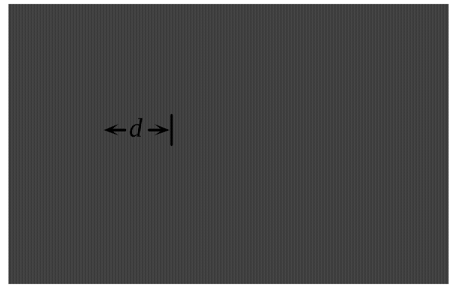
50. We find the rms speed from

$\text{KE} = !mv_{\text{rms}}^2 = 8kT;$

$(9.11 \times 10^{-31}\ \text{kg})v_{300}^2 = 3(1.38 \times 10^{-23}\ \text{J/K})(300\ \text{K})$, which gives $v_{300} =$ $1.17 \times 10^5\ \text{m/s}$.

$(9.11 \times 10^{-31}\ \text{kg})v_{2500}^2 = 3(1.38 \times 10^{-23}\ \text{J/K})(2500\ \text{K})$, which gives $v_{2500} =$ $3.37 \times 10^5\ \text{m/s}$.

51. We find the horizontal velocity of the electron as it enters the electric field from the accelerating voltage:



$!mv_0^2 = eV;$

$!(9.11 \times 10^{-31}\ \text{kg})v_0^2 = (1.60 \times 10^{-19}\ \text{C})(15 \times 10^3\ \text{V}),$

which gives $v_0 = 7.26 \times 10^7\ \text{m/s}$.

Because the force from the electric field is vertical, the horizontal velocity is constant. The time to pass through the field is

$t_1 = d/v_0 = (0.028\ \text{m})/(7.26 \times 10^7\ \text{m/s}) = 3.86 \times 10^{-10}\ \text{s}.$

The time for the electron to go from the field to the screen is

$t_2 = L/v_0 = (0.22\ \text{m})/(7.26 \times 10^7\ \text{m/s}) = 3.03 \times 10^{-9}\ \text{s}.$

If we neglect the small deflection during the passage through the field, we find the vertical velocity when the electron leaves the field from the vertical displacement:

$v_y = h/t_2 = (0.11\ \text{m})/(3.03 \times 10^{-9}\ \text{s}) = 3.63 \times 10^7\ \text{m/s}.$

This velocity was produced by the acceleration in the electric field:

$F = eE = ma_y$, or $a_y = eE/m$.

From the vertical motion in the field, we have

$v_y = v_{0y} + a_y t_1;$

$3.63 \times 10^7\ \text{m/s} = 0 + [(1.60 \times 10^{-19}\ \text{C})E/(9.11 \times 10^{-31}\ \text{kg})](3.86 \times 10^{-10}\ \text{s}),$

which gives $E =$ $5.4 \times 10^5\ \text{V/m}$.

52. We find the horizontal velocity of the electron as it enters the electric field from the accelerating voltage:

$!mv_0^2 = eV;$

$!(9.11 \times 10^{-31}\ \text{kg})v_0^2 = (1.60 \times 10^{-19}\ \text{C})(14 \times 10^3\ \text{V}),$

which gives $v_0 = 7.01 \times 10^7\ \text{m/s}$.

Because the force from the electric field is vertical, the horizontal velocity is constant. The time to pass through the field is

$t_1 = d/v_0 = (0.026\ \text{m})/(7.01 \times 10^7\ \text{m/s}) = 3.71 \times 10^{-10}\ \text{s}.$

The time for the electron to go from the field to the screen is

$t_2 = L/v_0 = (0.34\ \text{m})/(7.01 \times 10^7\ \text{m/s}) = 4.85 \times 10^{-9}\ \text{s}.$

The electron will sweep up and down across the screen. If we neglect the small deflection during the passage through the deflecting plates, when the electron leaves the plates the vertical velocity required to reach the edge of the screen is

$v_{y\text{max}} = h/t_2 = (0.15\ \text{m})/(4.85 \times 10^{-9}\ \text{s}) = 3.10 \times 10^7\ \text{m/s}.$

This velocity was produced by the acceleration in the electric field:

$F = eE_{\text{max}} = ma_{y\text{max}}$, or $a_{y\text{max}} = eE_{\text{max}}/m$.

From the vertical motion in the field, we have

$v_{y\text{max}} = v_{0y} + a_{y\text{max}} t_1;$

$3.10 \times 10^7\ \text{m/s} = 0 + [(1.60 \times 10^{-19}\ \text{C})E_{\text{max}}/(9.11 \times 10^{-31}\ \text{kg})](3.71 \times 10^{-10}\ \text{s}),$

which gives $E_{\text{max}} = 4.8 \times 10^5\ \text{V/m}$.

Thus the range for the electric field is $-4.8 \times 10^5\ \text{V/m} < E < 4.8 \times 10^5\ \text{V/m}$.

53. The energy density in the field is

$u = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}(8.85 \times 10^{-12}\ C^2/N\cdot m^2)(150\ V/m)^2 =$ $9.96 \times 10^{-8}\ J/m^3$.

54. (*a*) We find the potential difference from

$U = Q\,\Delta V$;

4.2 MJ = (4.0 C) ΔV, which gives $\Delta V =$ 1.1 MV.

(*b*) We find the amount of water that can have its temperature raised to the boiling point from

$U = mc\,\Delta T$;

4.2×10^6 J = m(4186 J/kg·C°)(100°C – 20°C), which gives $m =$ 13 kg.

55. (*a*) We find the average translational kinetic energy from

$KE_O = \frac{3}{2}kT = \frac{3}{2}(1.38 \times 10^{-23}\ J/K)(293\ K)/(1.60 \times 10^{-19}\ J/eV) =$ 0.039 eV.

(*b*) The average translational kinetic energy depends only on the temperature, so we have

$KE_N =$ 0.039 eV.

(*c*) For the iron atom we have

$KE_{Fe} = \frac{3}{2}kT = \frac{3}{2}(1.38 \times 10^{-23}\ J/K)(2 \times 10^6\ K)/(1.60 \times 10^{-19}\ J/eV) = 3 \times 10^2\ eV =$ 0.3 keV.

(*d*) For the carbon dioxide molecule we have

$KE_{CO_2} = \frac{3}{2}kT = \frac{3}{2}(1.38 \times 10^{-23}\ J/K)(223\ K)/(1.60 \times 10^{-19}\ J/eV) =$ 0.029 eV.

56. The acceleration produced by a potential difference of 1000 V over a distance of 1 cm is

$a = eE/m = eV/md = (1.60 \times 10^{-19}\ C)(1000\ V)/(9.11 \times 10^{-31}\ kg)(0.01\ m) = 2 \times 10^{16}\ m/s^2$.

Because this is so much greater than g, yes, the electron can easily move upward.

To find the potential difference to hold the electron stationary, we have

$a = g = eE/m$;

$9.80\ m/s^2 = (1.60 \times 10^{-19}\ C)V/(9.11 \times 10^{-31}\ kg)(0.030\ m)$, which gives $V =$ 1.7×10^{-12} V.

57. If the plates initially have a charge Q on each plate, the energy to move a charge ΔQ will increase the stored energy:

$\Delta U = U_2 - U_1 = (\frac{1}{2}Q_2{}^2/C) - (\frac{1}{2}Q_1{}^2/C)$

$= [(Q + \Delta Q)^2 - Q^2]/2C = [(2Q\,\Delta Q + (\Delta Q)^2]/2C = (2Q + \Delta Q)\,\Delta Q/2C$;

$8.5\ J = (2Q + 3.0 \times 10^{-3}\ C)(3.0 \times 10^{-3}\ C)/2(9.0 \times 10^{-6}\ F)$, which gives $Q = 0.024\ C =$ 24 mC.

58. (*a*) The kinetic energy of the electron ($q = -e$) is

$KE_e = -qV_{BA} = -(-e)V_{BA} = eV_{BA}$.

The kinetic energy of the proton ($q = +e$) is

$KE_p = -qV_{AB} = -(+e)(-V_{BA}) = eV_{BA} =$ 5.2 keV.

(*b*) We find the ratio of their speeds, starting from rest, from

$\frac{1}{2}m_e v_e{}^2 = \frac{1}{2}m_p v_p{}^2$, or $v_e/v_p = (m_p/m_e)^{1/2} = [(1.67 \times 10^{-27}\ kg)/(9.11 \times 10^{-31}\ kg)]^{1/2} =$ 42.8.

59. The mica will change the capacitance. The potential difference is constant, so we have

$\Delta Q = Q_2 - Q_1 = (C_2 - C_1)V = (K - 1)C_1 V$

$= (7 - 1)(2600 \times 10^{-12}\ F)(9.0\ V) = 1.4 \times 10^{-7}\ C =$ $0.14\ \mu C$.

60. If we equate the heat flow to the stored energy, we have

$U = \frac{1}{2}CV^2 = mc\,\Delta T$;

$\frac{1}{2}(4.0\ \text{F})V^2 = (2.5\ \text{kg})(4186\ \text{J/kg}\cdot\text{C°})(95°\text{C} - 20°\text{C})$, which gives $V =$ 6.3×10^2 V.

61. Because the charged capacitor is disconnected from the plates, the charge must be constant. The paraffin will change the capacitance, so we have

$Q = C_1V_1 = C_2V_2 = KC_1V_2;$

$24.0 \text{ V} = (2.2)V_2$, which gives $V_2 =$ 10.9 V.

62. The uniform electric field between the plates is related to the potential difference across the plates:

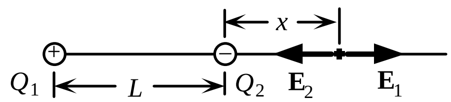
$E = V/d.$

For a parallel-plate capacitor, we have

$Q = CV = (Å_0A/d)(Ed) = Å_0AE$

$= (8.85 \times 10^{-12} \text{ C}^2/\text{N}\cdot\text{m}^2)(56 \times 10^{-4} \text{ m}^2)(3.0 \times 10^6 \text{ V/mm}) = 1.5 \times 10^{-7} \text{ C} =$ 0.15 μC.

63. (*a*) Because the charges have opposite signs, the location where the electric field is zero must be outside the negative charge, as shown.



The fields from the two charges must balance:

$kQ_1/(x + L)^2 = kQ_2/x^2;$

$(3.4\ \mu\text{C})/(x + 1.5 \text{ cm})^2 = (2.0\ \mu\text{C})/x^2,$

which gives $x = -0.65$ cm, 4.9 cm.

Because – 0.65 cm is between the charges, the location is

4.9 cm from the negative charge, and 7.4 cm from the positive charge.

(*b*) The potential is a scalar that depends only on the distance. If the potential is 0 at the point x from the negative charge, the potential for the two charges is

$V = k[(Q_1/|(x + L)|) + (Q_2/|x|)];$

$0 = [(3.4\ \mu\text{C})/|(x + 1.5 \text{ cm})|] + [(-2.0\ \mu\text{C})/|x|],$

which gives $3.4|x| = 2.0|(x + 1.5 \text{ cm})|$.

For a point between the two charges, x is negative, so we have

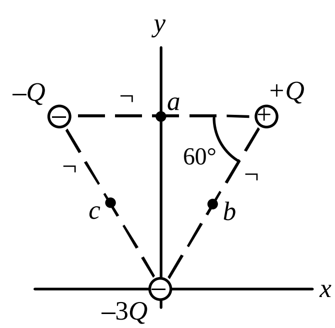
$3.4(-x_1) = 2.0(x_1 + 1.5 \text{ cm})$, which gives $x_1 = -0.56$ cm.

For a point outside the two charges, x is positive, so we have

$3.4(x_2) = 2.0(x_2 + 1.5 \text{ cm})$, which gives $x_2 = 2.1$ cm.

Thus there are two positions: 0.56 cm from the negative charge toward the positive charge, and 2.1 cm from the negative charge away from the positive charge.

64. The distances from the midpoint of a side to the three charges are ¬/2, ¬/2, and ¬ cos 30°.



At point *a*, we have

$V_a = k\{[(-Q)/(¬/2)] + [(+Q)/(¬/2)] + [(-3Q)/(¬ \cos 30°)]\}$

$= (kQ/¬)[(-2) + (+2) + (-3/\cos 30°)] =$ – 3.5 $kQ/¬$.

At point *b*, we have

$V_b = k\{[(+Q)/(¬/2)] + [(-3Q)/(¬/2)] + [(-Q)/(¬ \cos 30°)]\}$

$= (kQ/¬)[(+2) + (-6) + (-1/\cos 30°)] =$ – 5.2 $kQ/¬$.

At point *c*, we have

$V_c = k\{[(-3Q)/(¬/2)] + [(-Q)/(¬/2)] + [(+Q)/(¬ \cos 30°)]\}$

$= (kQ/¬)[(-6) + (-2) + (+1/\cos 30°)] =$ – 6.8 $kQ/¬$.

65. When the capacitors are connected, some charge will flow from C_1 to C_2 until the potential difference across the two capacitors is the same:

$V_1 = V_2 = V$.

Because charge is conserved, we have

$Q_0 = Q_1 + Q_2$.

For the two capacitors we have

$Q_1 = C_1V$, and $Q_2 = C_2V$.

When we form the ratio, we get

$Q_2/Q_1 = (Q_0 - Q_1)/Q_1 = C_2/C_1$, which gives $Q_1 = Q_0C_1/(C_1 + C_2)$.

For Q_2 we have

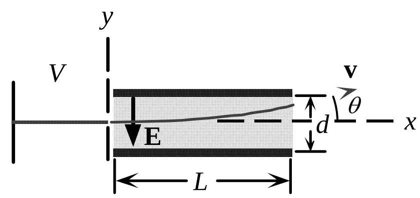
$Q_2 = Q_0 - Q_1 = Q_0\{1 - [C_1/(C_1 + C_2)]\}$, thus $Q_2 = Q_0C_2/(C_1 + C_2)$.

We find the potential difference from

$Q_1 = C_1V$;

$Q_0C_1/(C_1 + C_2) = C_1V$, which gives $V = Q_0/(C_1 + C_2)$.

66. We find the horizontal velocity of the electron as it enters the electric field from the accelerating voltage:



!$mv_0^2 = eV_{accel}$;

!$(9.11 \times 10^{-31}\ kg)v_0^2 = (1.60 \times 10^{-19}\ C)(25 \times 10^3\ V)$,

which gives $v_0 = 9.37 \times 10^7$ m/s.

We find the vertical acceleration due to the electric field from

$F = eE = ma_y$, or $a_y = eE/m = eV/md$;

$a_y = (1.60 \times 10^{-19}\ C)(250\ V)/(9.11 \times 10^{-31}\ kg)(0.013\ m) = 3.38 \times 10^{15}\ m/s^2$.

Because the force from the electric field is vertical, the horizontal velocity is constant. The time to pass through the field is

$t_1 = L/v_0 = (0.065\ m)/(9.37 \times 10^7\ m/s) = 6.94 \times 10^{-10}$ s.

From the vertical motion in the field, we have

$v_y = v_{0y} + a_yt_1 = 0 + (3.38 \times 10^{15}\ m/s^2)(6.94 \times 10^{-10}\ s) = 2.34 \times 10^6$ m/s.

The angle θ is the direction of the velocity, which we find from

$\tan\theta = v_y/v_0 = (2.34 \times 10^6\ m/s)/(9.37 \times 10^7\ m/s) = 0.025$, or $\theta = 1.4°$.

67. For the motion of the electron from emission to the plate, the energy of the electron is conserved, so we have

ÆKE + ÆPE = 0, or 0 – !$mv^2 + (-e)$ Æ$V = 0$;

– !$(9.11 \times 10^{-31}\ kg)v^2 + (-1.60 \times 10^{-19}\ C)(-3.02\ V - 0) = 0$, which gives $v = 1.03 \times 10^6$ m/s.

68. (*a*) For a parallel-plate capacitor, we find the gap from

$C = $ Å$_0A/d$;

$1\ F = (8.85 \times 10^{-12}\ C^2/N\cdot m^2)(1.0 \times 10^{-4}\ m^2)/d$, which gives $d = 9 \times 10^{-16}$ m.

Because this is many orders of magnitude less than the size of an atom, it is not practical.

(*b*) We find the area from

$C = $ Å$_0A/d$;

$1\ F = (8.85 \times 10^{-12}\ C^2/N\cdot m^2)A/(1.0 \times 10^{-3}\ m)$, which gives $A = 1.1 \times 10^8\ m^2$.

Because this corresponds to a square ≈ 10 km on a side, it is not practical.

69. Because the electric field points downward, the potential is greater at the higher elevation. For the potential difference, we have

$\Delta V = -(150\ \text{V/m})(2.00\ \text{m}) = -300\ \text{V}$.

For the motion of the falling charged balls, the energy is conserved:

$\Delta \text{KE} + \Delta \text{PE} = 0$, or $\frac{1}{2}mv^2 - 0 + q\,\Delta V + mg(0 - h) = 0$, which gives

$v^2 = 2gh - 2(q/m)\,\Delta V$.

For the positive charge, we have

$v_1^2 = 2gh - 2(q_1/m)\,\Delta V$

$= 2(9.80\ \text{m/s}^2)(2.00\ \text{m}) - 2[(550 \times 10^{-6}\ \text{C})/(0.540\ \text{kg})](-300\ \text{V})$, which gives $v_1 = 6.31\ \text{m/s}$.

For the negative charge, we have

$v_2^2 = 2gh - 2(q_2/m)\,\Delta V$

$= 2(9.80\ \text{m/s}^2)(2.00\ \text{m}) - 2[(-550 \times 10^{-6}\ \text{C})/(0.540\ \text{kg})](-300\ \text{V})$, which gives $v_2 = 6.21\ \text{m/s}$.

Thus the difference in speeds is 6.31 m/s – 6.21 m/s = 0.10 m/s.

70. (*a*) The energy stored in the capacitor is

$U = \frac{1}{2}CV^2 = \frac{1}{2}(0.050 \times 10^{-6}\ \text{F})(30 \times 10^3\ \text{V})^2 =$ 23 J.

(*b*) We find the power of the pulse from

$P = 0.10\ U/t = (0.10)(23\ \text{J})/(10 \times 10^{-6}\ \text{s}) = 2.3 \times 10^5\ \text{W} =$ 0.23 MW.

71. (*a*) We find the capacitance from

$C = \varepsilon_0 A/d$

$= (8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2)(110 \times 10^6\ \text{m}^2)/(1500\ \text{m}) = 6.49 \times 10^{-7}\ \text{F} =$ $0.649\ \mu\text{F}$.

(*b*) We find the stored charge from

$Q = CV = (6.49 \times 10^{-7}\ \text{F})(35 \times 10^6\ \text{V}) =$ 23 C.

(*c*) For the stored energy we have

$U = \frac{1}{2}CV^2 = \frac{1}{2}(6.49 \times 10^{-7}\ \text{F})(35 \times 10^6\ \text{V})^2 =$ $4.0 \times 10^8\ \text{J}$.