10.91 Problems

for Section 10.1,

10-1: The electrostatic force "F_{el}" between two point charges is 45 μN. What is F_{el} if **a)** the distance between the charges triples? **b)** one charge triples? **c)** one charge triples and so does the distance between them? **d)** both charges triple?

10-2: A –2.4 μC charge feels F_{el} = ↓ .36 N. At this location, **a)** What is the electric field [magnitude & direction]? **b)** What F_{el} and acceleration (if it was released) would be felt by a .00012 kg, +4.8 μC charge?

10-3: Two small metal balls (consider them to be "point objects"), each with equal charge and a mass of 4.0 grams, hang from .80 m long silk threads. The angle between the threads ( ) is 20°. How much charge is on each ball? What happens to the 20° angle if the charge on one ball is doubled, and the other ball's charge is cut in half? Will each ball now feel the same force?

10-4: In a hydrogen atom, the proton and electron are, on average, approximately .53 x 10^{-10} m apart. What are the electrostatic and gravitational forces acting on the electron? What is the ratio of these forces? { m_{proton} = 1.67 x 10^{-27} kg, $m_{electron}$ = 9.11 x 10^{-31} kg. }

On the atomic level (where "chemistry" occurs), which force is more important? In everyday situations (like walking across the room) which force is more important? Why?

==[do Pr w. .01% excess for two people (give ≈ # of ± if we assume all-water)?

10-5: An electron (9.11 x 10^{-31} kg) initially moving → at 5 x 10^7 m/s enters a 20 cm long region where E is 150000 N/C, ↓. How far does the electron move in the ↕ direction while it passes through this region?

10-6: When it is a distance "r" from a 350 nC point charge, a proton (1.67 x 10^{-27} kg) has an acceleration of 1.0 x 10^{13} m/s^2. What is E at this point? What is r?

At the location of the 350 nC charge, what E does the proton produce? Are the charges affected by equal E's? Do they feel equal F's?

10-7: Two "point objects" that are 2.0 cm apart have a total charge of +4.0 nC, and feel a repulsive force of 84.4 μN. What equation do you solve to get the charge on each object?

If objects with a total charge of +4.0 nC feel an attractive force of 6.41 mN, what equation do you solve to find their charges?

for Section 10.2,

10-8: Does the +3 charge exert the same force on the +2 charge in each situation?

10-9: What can you say (for certain) about the magnitude and ± sign of these charges,

Q_a **Q_b**

1) if E = 0 at a point between Q_a and Q_b?
2) if E = 0 at a point to the left of Q_a?

10-10: For each of these two situations,

is the electric field zero in region L, C or R?

Use ratio logic to find the location of each E = 0 spot, then check your answers by solving appropriate equations.

10-11: What is the electric field at "A". A and B are at the midpoints of a rectangle (50 cm x 110 cm) formed by the four charges. Hint: use symmetry logic to simplify the calculation.

Bonus: what F_{el} acts on the +8 μC charge?

for Section 10.3,

• **10-12**: Use the principles of "Electrostatics for Large Non-Point Objects" and "Induced Charge" to sketch the E lines for two large horizontal parallel conducting plates, with a metal ball in-between. The bottom and top plates have + and – charge. The sphere is uncharged and does not touch the plates.

If it was isolated, the neutral ball would not produce any E field. But with the plates there are E-lines going toward it and away from it. Does this contradict the principle of superposition, that "the E-field produced by Q exists independently of ... any other charge"? Explain.

10-13: Sketch the E field produced by four equal + charges at the corners of a rectangle ( ). { Hint: First draw E close to each charge, and at the midpoint of each rectangle-side. What is E at the rectangle's center, and far, far away?

• **10-14**: A very large conductor (like the earth) is called a *ground,* symbolized .

What is the charge (+, – or 0) on the metal sphere in each picture? When do electrons flow through the wire between the ball and ground? Which direction do they move? Does the square object have an excess of electrons, or a deficiency?

10-15: You have a + charged metal bar, and a neutral metal bar on a frictionless surface. How can you make the neutral bar move? What happens if you let the bars touch? How can you make the neutral bar move now?

10-16: If you have (as in Problem 10-##) a + charged bar and a "ground", how can you give two identical neutral metal spheres an equal-and-opposite charge? Can you give them equal charges of the same sign?

for Sections 10.4 and 10.5,

10-17: When a lightning bolt strikes a tree, the potential difference between cloud and tree may be 100 MV, with 40 C of charge being transferred. How much energy is carried by this one lightning bolt?

• **10-18**: Points A & B are at –5 V and +9 V, respectively. How much work is needed to move a –4 mC charged object from A to B at constant speed? What is the change in potential energy of the charge?

If this object weighs .032 N and is moving at 4.2 m/s when it is at A, what is its speed when it reaches B?

• **10-19**: A sphere with an 80 cm diameter has electric potential = –75 V. What is the sphere's net charge, how much work was needed to charge it, and what is the electric field at its surface? { Hint: Section 10.3 states that a sphere's E is the same as if the entire charge was a "point charge" located at the sphere's center. This principle is also true for V. }

10-20: If .15 J of work is needed to move a –20 mC object from one plate to the other, is the object moving to the plate with lower or higher potential? Is its potential energy decreasing or increasing? What is its change in potential and potential energy?

10-21: An alpha particle (double-charged helium atom whose 2-electron deficiency gives it $q = +3.20 \times 10^{-19}$ C) has a mass of 6.64×10^{-27} kg. If it accelerates from rest through a ΔV of 15 V, what is its final KE and v? What are the kinetic energies of a 30 eV alpha particle, and a 30 eV electron?

If it accelerates through a ΔV that is twice as large, what is the alpha particle's final v? To double its v, what ΔV is needed?

10-22: Which of the q's below has a + PE_{el}, if $PE_{el} \equiv 0$ when charges are infinitely far apart? Which q has the lowest PE, and the highest PE?

10-23: The earth has an electric field of about 100 N/C pointing toward its center. If we assume charge is distributed uniformly over its surface, how much net charge does the earth have? Do we have a shortage of electrons, or an excess? What is the earth's *charge density* in C/m^2 and $electrons/m^2$? { The earth is roughly spherical, with an average radius of 6.37×10^6 m. A sphere area is $4\pi r^2$. }

What is the earth's electric potential?

for Section 10.6,

10-24: Do Problem 10-10 but find the places where V (not E) is zero by using intuitive logic, ratio logic, and equations. #

10-25: Do Problem 10-11 but find V at A & B, and the work needed to move a
–3 μC point charge from B to A. #

10-26: What is the electrical potential energy of this charge configuration?

for Section 10.7,

• **10-27**: Between A and B, E points in the → direction: **A → B**. Which location is at lower potential? Does this location also have lower V-magnitude? What direction is F_{el} if an object has positive charge? negative charge? {Think about the EF and VF relationships. Do they both give the same answer? }

10-28: At each •, what is the direction of the electric field, and the F_{el} on an electron? At which • is E-magnitude largest? What is W_{el} in traveling from one • to another?

10-29: Draw equipotential surfaces for the equal-magnitude charges (– + , + +) at the start of Section 10.3, and the plates-and-ball in Problem 10-12. Then draw E-arrows for the picture in Problem 10-28. # #

10-30: If you know V (magnitude & ± sign), can you find E (magnitude & direction)?

If you know E (magnitude & direction), can you find V (magnitude & ± sign)?

10-31: Between two large metal plates that are 20 mm apart, a –3 μC charge feels a force of 3.6 mN, ↓. What is the potential difference between the plates? If the lower plate has V = 0, what is the upper plate's V?

10-32: If E can have units of N/C (because $E = F/q$) or V/m (because $E = \Delta V/d$), show that a Volt equals a [kg m^3] / [s^2 C].

What are the units of "k"?

10-33: Using facts-and-logic from Sections 10.3 & 10.7, show that every part of an electro- static surface is at the same potential.

A large and small sphere (60 cm and 40 cm radii) have charges of 10 C and zero. After they are connected by a wire, what is the net charge on each metal sphere?

10.92 Solutions

10-1: $F = kQq/r^2$. **a)** $F \propto 1/r^2$, so the multiplying factor is $1/3^2 = 1/9$; $45(\times 1/9) = 5$ N. **b)** $F \propto Q$, so $F = 45(\times 3) = 135$ N. **c)** Now the factors in a & b are combined; $F = 45(\times 1/9)(\times 3) = 15$ N. **d)** $F \propto Qq$, so $F = 45(\times 3)(\times 3) = 405$ N.

10-2: **a)** $F = qE$, so $E = F/q = .36/(2.4 \times 10^{-6}) =$ 150000 N/C. For a – charge, F & E point in opposite directions; F is ↓, so E is ↑.

b) A + charge feels F in the direction of E: ↑. $F_{el} = qE = (4.8 \times 10^{-6})(150000) = .72$ N. Or use ratio logic: if E stays the same and q doubles [from 2.4 μC to 4.8 μC], so does F [from .36 N to .72 N].

$a = F/m = .36/.0012 = 3000$ m/s per s.

10-3: The balls are motionless, $a_x = 0$ and $a_y = 0$. Both charges are equal so we'll call each of them "Q". Draw a picture, showing the forces acting on one ball:

$$F_x = m\,a_x:\ +(9 \times 10^9)\frac{Q^2}{(1.60 \sin 10°)^2} - T \sin 10° = 0$$

$$F_y = m\,a_y:\ +T \cos 10° - .040(9.8) = 0$$

Solve $F_y = ma_y$ for $T = .398$ N, substitute T into $F_x = ma_x$ and solve it for $Q = 7.70 \times 10^{-7}$ C $= 77$ μC.

Changing Q-and-Q to 2Q-and-$\frac{1}{2}$ Q doesn't affect the angle, because $kQq/r^2 = k(2Q)(\frac{1}{2}Q)/r^2$.

Both balls feel the same F_{el} (think about Newton's Third Law) even if the charges are unequal.

10-4: $$F_{el} = 9 \times 10^9 \frac{(1.6 \times 10^{-19})(1.6 \times 10^{-19})}{(.53 \times 10^{-10})^2} = 8.20 \times 10^{-8}\text{ N.}$$

$$F_{grav} = 6.67 \times 10^{-11} \frac{(1.67 \times 10^{-27})(9.11 \times 10^{-31})}{(.53 \times 10^{-10})^2} = 3.61 \times 10^{-47}\text{ N.}$$

F_{el} is larger by a factor of $(8.2 \times 10^{-8})/(3.61 \times 10^{-47}) = 2.27 \times 10^{39}$. An the atomic/chemistry level, F_{el} is much more important. When you walk across a room you feel F_{grav} (it keeps your steps from thrusting you up onto the ceiling!) but your muscle-action depends on chemistry and F_{el}. Both forces are important and necessary. F_{el} is not as dominant on the "large-object level" because most objects are electrically almost-neutral, with almost-equal amounts of + and – charge that cancel each other. But there is no "+ and – mass" that can cancel, so $F_{gravity}$ is more important for large objects; this is especially true on the astronomical level for stars, planets, moons,...

10-5: First analyze the → motion. The electron's → trip lasts $\Delta t = \Delta x / v_x = .20/(5 \times 10^7) = 4 \times 10^{-9}$ s.

E is ↓ and the electron has – charge, so F is ↑. We know 3-of-5 in the ↑ direction [$\Delta t = 4 \times 10^{-9}$ s, $a = F/m = qE/m = (1.6 \times 10^{-19})(150000)/(9.11 \times 10^{-31}) = 2.63 \times 10^{16}$ m/s², $v_i = 0$ because v_i is purely →] and want to find Δy. We can solve the "v_f-out" equation: $\Delta y = (0)t + \frac{1}{2}(2.63 \times 10^{16})(4 \times 10^{-9})^2 = .210$ m $= 21$ cm.

10-6: $E = F/q = ma/q = (1.67 \times 10^{-27})(1.0 \times 10^{13})/(1.6 \times 10^{-19}) = 104000$ N/C.

$E = kQ/r^2$, $104000 = (9 \times 10^9)(350 \times 10^{-9})/r^2$, and $r = .174$ m $= 17.4$ cm.

At a distance of 17.4 cm, the proton produces an E of $kQ/r^2 = k(1.6 \times 10^{-19})/.174^2 = 4.76 \times 10^{-8}$ N/C.

The proton is affected by a much larger E (104000 vs. 4.76×10^{-8}) but, because $F = qE$ and it has a much smaller q (1.60×10^{-19} vs. 350×10^{-9}), both charges will [as summarized in Newton's Third Law] feel equal-and-opposite forces. {The symmetry of "$qE_Q = QE_q$" is discussed in Section 10.1.}

10-7: If F is repulsive and Q_{total} is +, both charges are +. They can be represented by x and "4.0n – x", where "n" is a compact way to write "x 10^{-9}".

F	=	k Q q / r^2
84.4×10^{-6}	=	$(9 \times 10^9)(x)(4.0n - x)\,/\,(.02^2)$
84.4×10^{-6}	=	$+90000\,x \;\; -2.25 \times 10^{13}\,x^2$

$$(-2.25 \times 10^{13})\,x^2 + (-90000)\,x + (-84.4 \times 10^{-6}) = 0$$
$$a\,x^2 + b\,x + c = 0$$

Substitute a, b & c into the Quadratic Formula and solve for $x = 2.50 \times 10^{-9}$ (and $4.0n - x = 1.50 \times 10^{-9}$), or $x = 1.50 \times 10^{-9}$ (and $4.0n - x = 2.50 \times 10^{-9}$).

{Multiplying-and-dividing these numbers is more difficult than using numbers like 3, 4, 5,..., but it is regular arithmetic, so just be patient and careful.}

If F is attractive and Q_{toatl} is +, the larger charge is + and the smaller charge is –. Instead of adding to give 4.0n [as above, where (x) + (4.0n – x) = 4.0n], they subtract to give 4.0n: (4.0n + x) – x = 4.0n. Substituting into the $F = kQq/r^2$ equation gives

$$6.41 \times 10^{-3} = (9 \times 10^9)(x + 4.0n)(x)/.02^2$$

which can be solved, using the Q-formula, to give charges of 19 nC and 15 nC.

10-8: Yes. As stated in the superposition principle, the E and F produced by +3 exists independently of other charges. {The TOTAL F acting on +2 is, of course, different in the two situations.}

10-9: **1)** By exploring the possibilities thoroughly, you can conclude that Q_a & Q_b have opposite ± signs, but the "given information" provides no clues about their relative magnitudes.

2) Q_a and Q_b have opposite ± signs, and Q_b has a larger magnitude [so Q_a needs the "close" advantage].

10-10: If you draw your own pictures (showing E direction, distances,...) you'll be able to understand the following explanations more easily.

In Situation A [the top picture] the two E's point in opposite directions in the C-region, so this is where E can be zero. In "B" the E's are opposite in L and R, but (using "large vs. close" logic) their magnitudes can be equal (to give E = 0) only in L.

A: The –45 μC charge is "larger" by a factor of x9. If the E's have equal magnitude, the "close" factor ($1/r^2$) must give an advantage of x9 to the –5 μC charge. This occurs 10 cm to the right of "–5", where the r's are in a 1:3 ratio (a 10:30 split of the 40 cm).

B: Again, "–5" needs an advantage of x9. The 1:3 ratio occurs at a point 20 cm to the left of "–5", where the r's are 20 cm and 60 cm.

As in Problem 10-B, you can write these equations to find a place where the E-magnitudes are equal,

$$k(5\mu)/x^2 = k(45\mu)/(.40-x)^2$$
$$k(5\mu)/x^2 = k(45\mu)/(.40+x)^2$$

and solve them easily by taking the $\sqrt{\ }$ of both sides.

10-11: Symmetry: The +4's cause opposing E's (→ and ←) that are, because the Q's are equal and A is the same distance from them, equal in magnitude. These two E's cancel each other.

Similar logic shows that the ↕ components of the E caused by +8 ( ) and –8 ( ) cancel each other. But the x-components both point →: they add to give $E_x = 2[k(8 \times 10^{-6})/(.743^2)] \cos 42.3° = 1.93 \times 10^5$ N/C. {Use basic geometry & trig to find .743 m & 42.3°.}

There are no "symmetry shortcuts" for finding the F_{el} on "+8". Use the same strategy as in Problem 10-A.

$F_x = (+.476) + (-.393 \cos 24.4°) = +.118$ N,

$F_y = (+1.152) + (-.393 \sin 24.4°) = +1.314$ N,

$F_{total} = 1.319$ N, $\theta = 5.13°$ (F is "almost pure-y").

10-12: As shown below, – and + charge is induced to the bottom and top of the ball, respectively. First draw E lines (they are "solid" below) pointing ⊥ away from the plates and ball, then estimate (as shown by - - - lines) how these lines "connect" with each other.

Far from the ball, E lines go straight ↑ from the bottom to top plate. But near the ball, the lines "bend" so they blend smoothly with the contours formed by the three E-lines that go to-and-from the ball.

The E-field of the uncharged ball is consistent with "superposition". The charged plates makes ball-charge move, and this causes the change in E. {if we could "fix" the ball's induced charge distribution so it would not move, and then removed the plates, the E-field in the space near the ball would stay the same as it was when the plates were present.} ==[is {} nec?

10-13: E points radially away from each charge; I've arbitrarily chosen five E-lines per charge. At each midpoint, "symmetry logic" [as in Problem 10-##] can be used to show that E points straight away from the center, as shown by the ⇐ ⇑ ⇒ ⇓ arrows. At the center, use symmetry logic: E = 0. Far away, E points radially away from a "point charge" of +4Q.

It is easy to know E at these special points: close, at midpoints, at center, far. Use "what you know for certain" to help you guess what happens in-between, using trial-and-error (draw with pencil & eraser). For many purposes, you don't need to worry about exact shapes, just do the best you can. The shapes below are not totally accurate, but they give a reasonable idea of the approximate shape of the overall pattern.

10-14: **a)** $Q_{ball} = 0$; the ground will "draw" charge from the sphere to neutralize it. **b)** Now – charged electrons are pulled upward because they are attracted by the + charged square bar, so Q is –. **c)** The ball has the same – charge it did in "b". **d)** The + bar (the "reason" for the ball's induced charge) is gone, but the – charges cannot escape because the wire running to the ground has been broken. Q is same as in "b".

Between a & b, electrons move ↑ onto the sphere.

The bar has a deficiency of electrons (– charge), so there are more +'s than –'s, giving it a net + charge.

10-15: With nonconducting gloves (so its + charge doesn't move onto your body) hold the + bar close to the neutral bar. This causes induced charge separation in the neutral bar, . The right end of the neutral bar (which is – charged) is now attracted by the nearby + bar, and it will feel F in the → direction.

You can maintain this → force by moving the + bar → as the neutral bar moves →. But if you let the bars touch, some + charge flows onto the neutral bar, giving it a net + charge, . Now you can use repulsive force to "push" the bar ←.

10-16: Touch the spheres together, then bring the bar close to one ball, , thus inducing the charges shown. Then separate the balls, , and remove the metal bar. The spheres were initially uncharged, so the electrons one ball gains, the other loses. This *conservation of charge* gives them equal and opposite charges.

To give the spheres equal-and-alike charges, touch them together and bring in the + bar, as above. Then separate the balls, remove the + bar, and neutralize the + ball by touching it to the ground. Touch this neutral ball to the – ball, and half of its – charge will be on each ball. {To give them equal + charges, which step in the procedure would you change?}

10-17: The magnitude of W_{el} (ignoring ± signs) is $W_{el} = q\,\Delta V = (40)(100 \times 10^6) = 4$ billion Joules!

10-18: $W_{el} = -q\,\Delta V = -(-4 \times 10^{-3})[(+9) - (-5)] = +.056$ J. If speed is constant, $\Delta KE = 0$, $W_{total} = 0$, and $W_{you} = -W_{el} = -(+.056 \text{ J}) = -.056$ J. The W you do is –; you must "restrain" the charge, holding it back so its speed doesn't increase.
$\Delta PE_{el} = -W_{el} = -.056$ J.

The object's mass is w/g = .032/9.8 = .00327 kg.
If the object is released, $W_{you} = 0$, and

$$W_{el} + W_{you} = \tfrac{1}{2}\, m\, v_f^2 - \tfrac{1}{2}\, m\, v_i^2$$
$$(+.056) + 0 = \tfrac{1}{2}(.00327)\, v_f^2 - \tfrac{1}{2}(.00327)(4.2)^2$$
$$7.2 \text{ m/s} = v_f$$

10-19: $V = Q/r$, so $Q = Vr = (-75)(.40) = -30$ C.
The magnitude of W (ignoring ± signs) is $q\,\Delta V = 30(75) = 2250$ J.
$E = Q/r^2 = 30/.40^2 = 188$ N/C, toward the center.

10-20: If "work is needed", the – charge is moving in the "uphill (un-natural) direction" toward – charge and a lower number-line V. And "uphill" means that PE increases. ΔV is – and ΔPE is +, as predicted by $\Delta PE = q\,\Delta V$ and the fact that q is –.

If you do .15 J of work, and we assume $\Delta KE = 0$, $W_{el} = -W_{you} = -(+.15 \text{ J}) = -.15$ J. $W_{el} = -q\,\Delta V$, $\Delta V = -W_{el}/q = -(-.15)/(-20 \times 10^{-3}) = -7.5$ V.
$\Delta PE = q\,\Delta V = (-.020)(-7.5) = +.15$ J.
A check: $\Delta PE = -W_{el} = -(-.15 \text{ J}) = +.15$ J. OK.
The ± signs show that, as concluded using intuitive reasoning above, ΔV is –, and ΔPE_{el} is +.

10-21: If the α-particle accelerates from rest, we know W_{total} is + and we don't have to think about the ± signs in "$W = -q\,\Delta V$": $W_{el} = (3.20 \times 10^{-19})(15) = 4.8 \times 10^{-18}$ J. This W makes KE increase from 0 to $\tfrac{1}{2}(6.64 \times 10^{-27})\, v_f^2$, so $v_f = 3.80 \times 10^4$ m/s.
The α-particle's final KE is 4.8×10^{-18} J.

(30 eV)[(1.60 x 10^{-19} J]/(1 eV)] = 4.8 x 10^{-19} J. A "30 eV object" has 4.8 x 10^{-19} J of KE, whether it is an electron accelerating through 30 V, or an alpha particle (with twice as much charge) accelerating through 15 V.

Ratio logic: If $KE_i = 0$, $q\,\Delta V = \tfrac{1}{2}\, m\, v_f^2$. When ΔV doubles, so does v_f^2, but v_f only increases by a factor of $\sqrt{2} = 1.414$, and $v_f = 1.414(38000) = 53700$ m/s.
When v_f doubles, v_f^2 increases by a factor of 4, and so does ΔV: $\Delta V = 4(15 \text{ V}) = 60$ V. ==[maybe split the early part and ratio logic into two problems]

10-22: When a +q moves closer to –Q, in the direction it naturally wants to go, it moves "downhill" in PE, from 0 [at ∞] to a negative value. But the –q's must move "uphill", so they have a PE_f that is higher than the zero they had at ∞ separation.
A & B (with +q) have PE_f that is –, while C & D (with –q) have PE_f that is +.

B & D have the largest PE magnitude, because q is closer to Q. B has "lowest" PE (most negative on the number-line). D has the highest (most positive) PE.

10-23: $Q = Er^2 = 100(6.37 \times 10^6)^2 = 4.1 \times 10^{15}$ C.
E points inward, so Q is –. Earth has an excess of negative-charged electrons.
Charge density = $Q/A = (4.1 \times 10^{15})/4\pi(6.37 \times 10^6)^2 = 7.8$ C/m^2. (7.8 C)(1 electron / 1.60 x 10^{-19} C) = 4.9 x 10^{19} electrons: Q-density = 4.9 x 10^{19} els/m^2.

If we define V ≡ 0 for an earth that is neutral, then $V_{earth} = Q/r = (4.1 \times 10^{15})/(6.37 \times 10^6) = 6.4 \times 10^8$ volts, 640 million volts! {Only ΔV is important, so this high voltage doesn't == any danger.}
==[is this correct ?? it's very high

10-24: In Situation A, both – charges produce – V, so V cannot be 0 except at ∞ distance away where $V = Q/r^2 = Q/\infty^2 \approx 0$.
Large-and-close logic shows that V can be 0 in the L or C regions. As in Solution 10-10, "–5" needs a close-factor (= 1/r, instead of 1/r^2) of x9. This occurs 4 cm to the right of "–5", where the r's are in a 1:9 ratio (a 4:36 split of the 40 cm). It also occurs 5 cm to the left of "–5", where the r's are 5 cm and 45 cm.
Notice that ratios of 1:3 on either side of the small charge, at distances of 1/2(40 cm) and 1/4(40 cm). Ratios of 1:9 occur at distances of 1/10(40 cm) and 1/8(40 cm). Do you see the numerical relationships? If you study the diagrams (or equations) you'll find the logical reasons.
{ 2 ← 3 → 4, 8 ← 9 → 10 }

As in Problem 10-10, you can solve equations to find places where the V-magnitudes are equal:

$$k(5\mu)/x = k(45\mu)/(.40 - x)$$
$$k(5\mu)/x = k(45\mu)/(.40 + x)$$

10-25: Symmetry: The +8 and –8 produce equal and opposite V at A and at B, so these V's cancel each other. $V_A = 2(4 \times 10^{-6})/.55 = +1.45 \times 10^{-5}$ V, and $V_B = 2(4 \times 10^{-6})/.743 = +1.08 \times 10^{-5}$ V.

The V at A is more +, so we expect that a –3 mC charge will "want" to go from B to A. You'll have to restrain the charge (not push it), so W_{you} will be – .

$W_{el} = -q\Delta V = -q[V_f - V_i] = -q[V_A - V_B] = -(-3 \times 10^{-6})[(+1.45 \times 10^{-5}) - (1.08 \times 10^{-5})] = 1.11 \times 10^{-11}$ J. If we assume [as usual] that the charge is moved at constant v, $\Delta KE = 0$, $W_{total} = 0$, and $W_{you} = -W_{el} = -1.11 \times 10^{-11}$ J.

10-26: To calculate PE, consider all interactions:

$PE_{4\text{-and-}5} = (9 \times 10^9)(+4\mu)(-5\mu)/(.030) = -6.00$ J,
$PE_{4\text{-and-}3} = (9 \times 10^9)(+4\mu)(+3\mu)/(.070) = +1.54$ J,
$PE_{5\text{-and-}3} = (9 \times 10^9)(-5\mu)(+3\mu)/(.040) = -3.38$ J,
$PE_{total} = (-6.00) + (+1.54) + (-3.38) = -7.84$ J.

PE is – because favorable interactions (+4 with –5, –5 with +3) contribute more to PE_{total} than the unfavorable interaction (+4 with +3).

10-27: E points "downhill in V", so B has lower number-line V. But B doesn't necessarily have lower V-magnitude; for example, their potentials could be +3 V and –5 V, or –10 V and –15 V.

For a + charge, F_{el} points in the direction of E (→) and toward lower number-line V (→). For a – charge, F_{el} points opposite E (←) and toward higher V (←).

10-28: E points ⊥ to an equipotential surface, toward lower V. At the left, center & right locations, E points ↗, ↓ and ←. An electron has – charge, so the F acting on it points opposite to E: , ↑ and →.

E = –ΔV / d, so E is large at locations where ΔV changes a lot during a small d. The equal-V lines are closer together at the right • (in a short distance as we move ←, V changes from –5 V to –20 V) so this • has a larger E than the other • locations.

{All three •'s have the same V (it is –10 V) but their <u>rate of V-change (with position)</u> is different.}

Since all three •'s are at the same potential [–10 V], $W = -q\Delta V = -q(0) = 0$. Also: as described in Section 10.7, during movement along an equipotential surface E (and thus F) is ⊥ to d, so $W = F_{||}\, d = (0)\, d = 0$.

10-29: An equal-V surface (- - -) is always ⊥ to E,

E is always ⊥ to the equal-V surfaces, and points in the direction of decreasing V.

10-30: No. E is related to ΔV, but not to V. {If V is large, E can be large, small or zero, pointing in any direction.}

No. ΔV (but not V) is related to E. {If E is large, ΔV/r decreases quickly as you move in the direction of E, but V can be large, small or zero, + or –.}

10-31: $\Delta V = E\,d = (F/q)\,d = [(3.6m)/(3\mu)](.020) = 24$ V. q is – and F is ↓, so E is ↑, and V decreases during a ↑ movement [in the direction of E] from the bottom plate to top plate. If the bottom plate is at 0 V, the top plate is at –24 V.

10-32: Both E-units are equivalent: N/C = V/m, Nm/C = V *, and V-units = Nm/C = (kg m / s^2)(m)/C = kg m^3 / s^2 C. *Analyzing the units of "$W = -q\,\Delta V$" leads to the same conclusion: $V = -W/q$, so V-units = W-units / q-units = J / C = Nm / C.

Use any equation with k: $F = kQq/r^2$, $E = kQ/r^2$, $W = -kQq/r$, $V = kQ/r$. If we choose $V = kQ/r$, the unit-equation is "(kg m^3 / s^2 C) = (k-units)(C)/(m)", and k-units are (kg m^4) / (s^2 C^2) = N m^2 / C^2.

10-33: As stated in Section 10.3, E is always ⊥ to a conductor's surface, so $W = F_{||}\, d = (q\, E_{||})\, d = (0)\, d = 0$, and $\Delta V = -W_{el} / d = 0 / d = 0$.

Alternative logic: if there is ΔV within a conductor, then – charged electrons (which are free to move) will move toward higher V. But in an electro<u>static</u> conductor, charges are (by definition) not moving, so we can conclude that ΔV = 0 within the conductor.

If charges are moving, is a conductor electrostatic? {This question is discussed in Problem 11-##.}

After the large & small metal spheres are connected, they are a "continuous conductor" that has the same V. If "x" is the charge that moves onto the small sphere, a charge of "10 – x" remains on the large sphere.

$$V_{large\ sphere} = V_{small\ sphere}$$
$$k(10 - x)/.6 = k(x)/.4$$
$$4 - .4x = .6x$$

Solving: x = 4 C (net charge on small sphere),
10 – x = 6 C (charge on large sphere).

As common sense would lead you to expect, a large sphere has a larger "capacity" to hold charge, if both spheres have the same ΔV. {The charge-holding capacity of conductors is explored in Chapter 11.}