Exam I: Chapters 14–15

1. How do we know charge exists?
   A) We don't. Any effects or manifestations that are attributed to "charge" can just as easily be explained by applying the known effects of gravity on masses.
   B) Charge can only be detected by ultra-sensitive instruments. It wasn't until the electron was discovered in 1897 that anyone even suspected that there was any such thing as electric charge.
   C) Electric charges glow. If you see a glow, charge is present. If there's no glow, there's no charge. Things that glow also tend to be pretty hot, so it was historically very difficult to safely investigate this weird phenomenon.
   D) The effects of static charge are readily apparent, and have been noted for literally thousands of years. That the electrostatic force can either attract or repel is a definite indicator that you are not seeing the result of gravity.

2. True or false: Because a charged object can move a magnetic compass needle, it can be concluded that electric charge has some relationship with magnetism.

3. How do we know that charge is not a fluid permeating all matter?
   A) Because not everything is wet.
   B) Shrug. It might be. If it's a colorless, odorless, tasteless, massless fluid, then how are you going to measure it?
   C) The fluid hypothesis was definitively disproved at the beginning of the 20th century, when the electron was discovered and shown to be a particle having a small (but measurable) mass, and a small (but measurable) charge.
   D) The fluid hypothesis is probably correct. The fact that scientists occasionally refer to the free valence electrons of interacting metallic atoms as a "sea of electrons" proves it.

4. Compare the charges on protons and electrons.
   A) Both particles carry the same amount of positive charge.
   B) Both particles carry the same amount of negative charge.
   C) The particles carry the same quantity of charge, but protons are (+) and electrons are (–).
   D) Protons, being far larger, carry far more charge than electrons. Electrons are (+), and protons are (–).

5. According to the principle of **charge quantization**,
   A) an object might carry $-1.6\text{x}10^{-19}$C of excess charge, but never $+1.6\text{x}10^{-19}$C of excess charge.
   B) an object might carry $\pm n(1.6\text{x}10^{-19})$C of excess charge, where n must be an integer value.
   C) an object might carry $\pm n(1.6\text{x}10^{-19})$C of excess charge, where n may be any real number.
   D) every proton carries an identical charge, but the charge on an electron may vary.

6. What is most responsible for making dielectrics (insulators) poor conductors of charge?
   A) A full valence shell makes it difficult to move electrons from atom to atom.
   B) The high density of most insulators effectively prevents the movement of any charges.
   C) They have a crystal structure; the long–range order makes it difficult to move electrons.
   D) They typically have heavy nuclei: The more protons in the nucleus, the more difficult it becomes to pull protons out of the nucleus and pass them from atom to atom.

7. According to the principle of **charge conservation**,
   A) charges must always exist in pairs of one negative and one positive charge.
   B) removing a charge (electron or proton) from an atom instantly causes the creation of a new equivalent charge to replace it.
   C) charge cannot be created or destroyed. Charges can be moved or transferred between objects, but with no net change in the overall quantity of charge.
   D) when a proton and electron come together, the particles annihilate because the net charge will be zero.

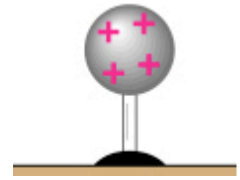
8. By scuffling across the carpet, you accumulate an excess charge of $-2.0\text{x}10^{-19}$C.
   A) This is a dangerous amount of charge. You will definitely be electrocuted when you touch the light switch.
   B) This is pretty substantial, but not lethal. Don't touch the kitty's nose, that's just mean.
   C) This is a very small amount of charge. If you touched the light switch, you might feel a very small shock.
   D) This is a trick question. You cannot accumulate an excess negative charge.
   E) This is a trick question. You can accumulate a negative charge, just not this particular quantity of negative charge.

9. True or false: To ionize a sodium atom, remove one or more protons from its nucleus.

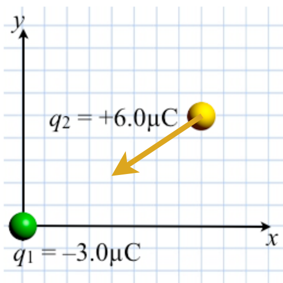
10. If you charge a plastic rod or comb by rubbing it with a wool cloth, you are
    A) using conduction to move negative charges from the rod to the cloth.
    B) using induction to move positive charges from the cloth to the rod.
    C) using friction to move negative charges from the cloth to the rod.
    D) using pair production to create new proton-antiproton pairs. The protons stay on the cloth (positive) and the anti-protons move to the rod, making it negative.
    E) experiencing a hallucination. Charges cannot be moved; that is the fundamental principle of charge conservation!!

11. If you stick a negatively charged balloon to the wall, you are
   A) using conduction to move positive charges from the balloon to the wall.
   B) using induction to move negative charges deeper within the wall.
   C) using friction to move positive charges from the wall to the balloon.
   D) using pair production to create new proton-antiproton pairs. The protons stay on the wall (positive) and the anti-protons move to the balloon, making it negative.
   E) experiencing another hallucination. Charges conservation dictates that charges cannot be moved!

12. How did you get that aluminum sphere to be positively charged?



   A) Easy. First I pulled some protons off the nuclei of the carbon atoms in my graphite rod. Then I touched the positively charged rod to the metal sphere. Next question?
   B) I connected the electrically neutral sphere to the ground with a copper wire. Because copper is a conductor, electrons from the sphere naturally want to travel to ground.
   C) Just connecting a ground wire is insufficient. You also need a second wire, attached to a voltage source. Power up the source, and the sphere charges automatically.
   D) First I polarized the sphere by holding a negatively charged rod close (but not touching) to the left side. When negative charges are repelled to the right, I attached a grounding wire to conduct them away from the sphere.
   E) None of these answers will result in a positively charged sphere. The (+) on the sphere are just the sign convention leftover from the 1800s, before anyone knew that electrons existed and were negatively charged.



Charge $q_1 = -3.0\mu C$ is positioned at the origin (0, 0). Charge $q_2 = +6.0\mu C$ is fixed at (0.80m, 0.50m).

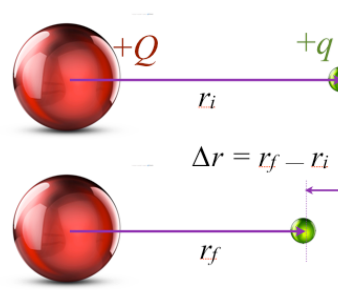
13. What is the **direction** of the force on q_2 because of q_1?
   A) The force has only a $+x$ component.
   B) The force has only a $+y$ component.
   C) The force has $+x$ and $+y$ components.
   D) The force has $+x$ and $-y$ components.
   E) The force has $-x$ and $-y$ components.
   F) The force has $-x$ and $+y$ components.

14. True or false: Replacing the original charge q_2 with a new charge, $q_2 = +12.0\mu C$ will result in a new force that has twice the magnitude of the original force.

15. Now assume that the two **original charges** are back in their **initial locations**, as shown on the figure. Charge q_2 is moved to a new location such that it is exactly **three times farther away** from q_1 than its initial position. The new force on q_1
   A) decreases to 1/9 its previous magnitude.
   B) decreases to 1/3 its previous magnitude.
   C) increases by a factor of 3.
   D) increases by a factor of 9.

16. Compare the force of gravity on an electron orbiting a single proton (a hydrogen atom!) to the electrostatic force on the electron due to the proton.
   A) They are equal. Both forces are exactly 1N, and both point radially outward, away from the proton.
   B) The forces do share the same direction; both forces point radially inwards, towards the proton. However, the force due to gravity is about 40× larger than the electrostatic force in magnitude.
   C) Both forces do point radially toward the proton, but the electrostatic force is enormous, compared to gravity. The magnitude of the electrostatic force is roughly $10^{39}\times$ larger than gravity!

17. Two charges have the same sign, but the different magnitude. The work required to move $+q$ closer to $+Q$, from a position r_i to r_f, is shown on the right. What's wrong with this picture?
   A) Nothing. Looks completely correct!
   B) Everything. If the charges are both (+), then they should be the same size. And the definition of work isn't *force·distance*, it's *force×distance*.
   C) Something. The equation is incorrect. You cannot just multiply the force and distance, because the force is constantly changing!

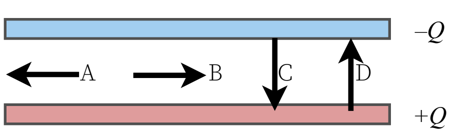


$$W = F \cdot d = \left[k\frac{Qq}{r_i^2} \right](r_f - r_i)$$

18. If $Q = +20\mu C$ and $q = +5\mu C$, how much work will be done to move q from ∞ to a position $r = 0.05\text{m}$ from Q?

$$W = \frac{kqQ}{r} = \frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(20\times10^{-6}\text{C})(5.0\times10^{-6}\text{C})}{(0.05\text{m})} = 18\text{J}$$

   A) $W = 0\text{J}$
   B) $W = 2\text{J}$
   C) $W = 5\text{J}$
   D) $W = 9\text{J}$
   E) $W = 18\text{J}$
   F) $W = 20\text{J}$



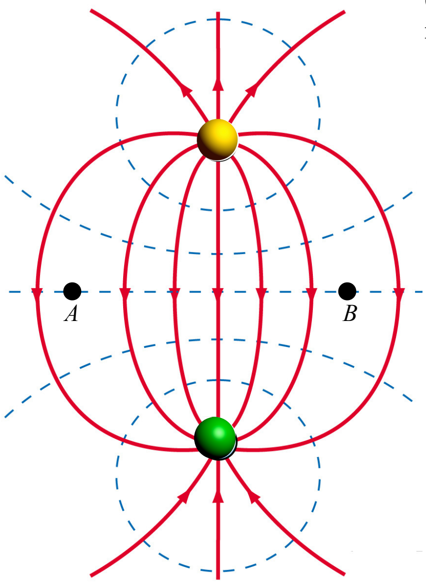
Two conducting plates are arranged parallel to each other as shown. The plates are charged as labeled with Q=3.5μC. The plates have an area $A = 0.07\text{m}^2$.

19. Which arrow shows the direction of the electric field vector? D

20. Decreasing the plate separation will
    A) have no effect on the magnitude E of the field.
    B) increase the magnitude of the electric field.
    C) decrease the magnitude of the electric field.
    D) change the direction of the field from A to B.
    E) change the direction of the field from C to D.
    F) change both the magnitude and direction of $\boldsymbol{E}$.

21. To double the **electric field** E between these two plates, you should
    A) double the quantity of charge, from Q to $2Q$.
    B) halve the quantity of charge, from Q to ½Q.
    C) double the plate area from A to $2A$.
    D) halve the plate area from A to ½A.
    E) **do either A or D, but not both.**
    F) do both B and C, but not separately.

22. To double the **potential difference** ΔV between these two plates, you should
    A) double the electric field, from E to $2E$.
    B) halve the electric field, from E to ½E.
    C) double the plate separation from d to $2d$.
    D) halve the plate separation from d to ½d.
    E) **do either A or C, but not both.**
    F) do both B and D, but not separately.



On the figure on the left, two opposite point charges $+Q$ and $-Q$ are separated by a fixed distance $\boldsymbol{r}$. Answer Questions 24 – 30 using this figure.

23. The electric field lines
    A) **are represented by the solid lines.**
    B) are represented by the dotted lines.
    C) are single points located exactly where the point charges are located.
    D) are represented by the empty spaces between both sets of lines.
    E) are non-existent. Point charges do not create electric fields.

24. True or false: There is not enough information on this diagram to uniquely determine the sign of either charge.

25. True or false: The field strength is zero at the point exactly halfway between the charges.

26. True or false: The solid lines indicate the path that a positive test charge would follow if it was released at some point on a specific line.

27. True or false: A negative charge placed exactly half way between the point charges will be in equilibrium: It will not move in any direction.

28. The equipotentials
    A) are represented by the solid lines.
    B) **are represented by the dotted lines.**
    C) are single points located exactly where the point charges are located.
    D) are represented by the empty spaces between both sets of lines.
    E) are non-existent. There are no equipotentials possible for the configuration of charge shown.

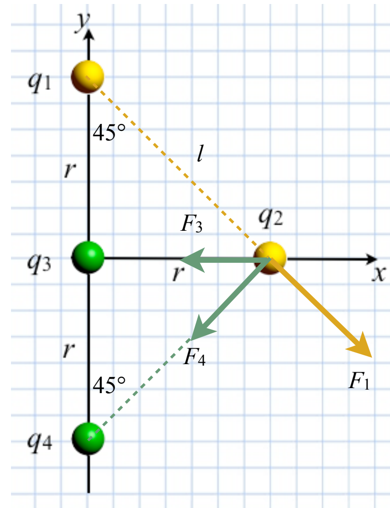
29. A positive test charge $+q$ is placed at point A. How much work will be done to move the charge along the dotted line, from point A to point B?
    A) None! There is no potential difference from A to B!
    B) $W = qV$: Multiply the charge q by the voltage of the equipotential.
    C) $W = Ed$: Multiply the magnitude of the electric field by the distance d between the fixed charges $+Q$ and $-Q$.
    D) $W = (F_x)x$: Multiply the $\boldsymbol{x}$-component of the force on the test $\boldsymbol{q}$ due to the fixed charges by the distance $\boldsymbol{x}$ from A to B.
    E) There's no way to calculate this, because to be complete, you would have to include the work done by both the electric field and the gravitational field–and we have no idea what the gravitational field looks like (whether the path is a vertical circle or a horizontal circle!

30. What does it mean to say "electrons fall up?"
    A) Electrons are not subject to gravitational forces.
    B) An electron will fall away from a positive charge, from higher potential to lower potential.
    C) **An electron will fall away from another negative charge, from lower potential to higher potential.**
    D) An electron will fall toward another negative charge, from a higher potential to a lower potential.
    E) Nothing, really. It's a cliché, like saying "It's raining cats and dogs!" Nobody really thinks that several species of small furry animals are falling out of the sky.

Part II: Problem Solving

Solve each of the following problems to the best of your ability. Please work in the space provided, and if you need scratch paper, it will be provided for you. Please work as neatly as you can, and make your reasoning/logic/math as clear as possible.

31. Four point charges are positioned as shown on the right. Charges q_1 and q_2 are both positive, and $q_1 = q_2 = +6.0$ nC. The charges q_3 and q_4 are both negative, and $q_3 = q_4 = -3.0$nC. The distance $r = 0.15$ m.
    A) (5 points) Sketch the forces acting on charge q_2, due to the other three charges. Be very careful with the vector directions.
    B) (5 points) Use Coulomb's Law to find the net force acting on q_2. Express your answer in the form of the **vector components** F_x and F_y. Answer with three sig figs.



$$r^2+r^2=l^2 \implies l^2=2r^2=2(0.15\text{m})^2$$

$$F_{1x}=+\frac{kq_1q_2}{l^2}\cos45° = \frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(6\times10^{-6}\text{C})(6\times10^{-6}\text{C})}{2(0.15\text{m})^2}\cos45° = +5.09\text{N}$$

$$F_{1y}=-\frac{kq_1q_2}{l^2}\sin45° = -\frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(6\times10^{-6}\text{C})(6\times10^{-6}\text{C})}{2(0.15\text{m})^2}\sin45° = -5.09\text{N}$$

$$F_{3x}=-\frac{kq_2q_3}{r^2} = -\frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(6\times10^{-6}\text{C})(3\times10^{-6}\text{C})}{(0.15\text{m})^2} = -7.20\text{N}$$

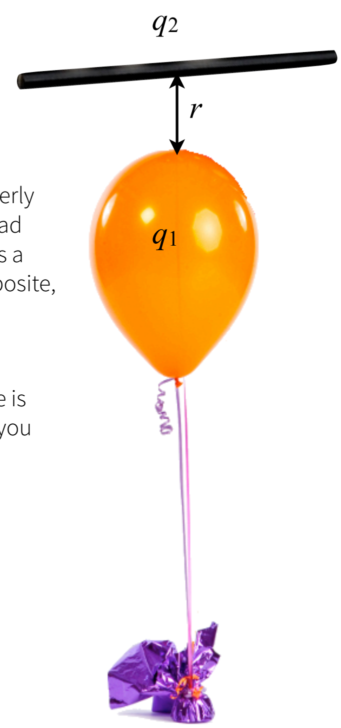
$$F_{4x}=-\frac{kq_2q_4}{l^2}\cos45° = \frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(6\times10^{-6}\text{C})(3\times10^{-6}\text{C})}{2(0.15\text{m})^2}\cos45° = -2.55\text{N}$$

$$F_{4y}=-\frac{kq_2q_4}{l^2}\sin45° = -\frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(6\times10^{-6}\text{C})(3\times10^{-6}\text{C})}{2(0.15\text{m})^2}\sin45° = -2.55\text{N}$$

$$\sum F_x = F_{1x}+F_{3x}+F_{4x} = +5.09-7.20-2.55 \implies F_x = -4.66\text{N}$$

$$\sum F_y = F_{1y}+F_{3y}+F_{4y} = -5.09+0-2.55 \implies F_y = -7.64\text{N}$$

32. An air-filled balloon with mass $m = 25\text{g}$ is tethered to the ground by a ribbon. The balloon carries charge $q_1 = -3.5\mu\text{C}$. A glass rod carrying $q_2 = +2.0\mu\text{C}$ of charge is held above the balloon, at a distance of $r = 0.30\text{m}$.
   - A) (5 points) Sketch the force diagram for the balloon. Be sure to label the forces clearly.
   - B) (5 points) Determine the tension in the ribbon. Answer with three sig figs.



Note: what I **meant** and what I **typed** were not the same thing! If you solved the problem properly using the nano-Coulomb charges, your result wouldhave been a tension $T = -0.245\text{N}$. If you had properly oriented the tension in the down direction at the beginning, that negative at the end is a warning. You should not get a negative value, because that flips the vector direction to the opposite, which is up. And the ribbon *has* to pull down, it *can't* push the balloon up.

If you ended up at $T = -0.245\text{N}$, then you did receive full credit.

What I meant to type was μC, not nC of charge. The nano-C charges are not enough! The force is smaller than the weight of the balloon. With the micro-C charges, you have enough force that you need the ribbon to tether the balloon. Here is the problem I meant you to solve:

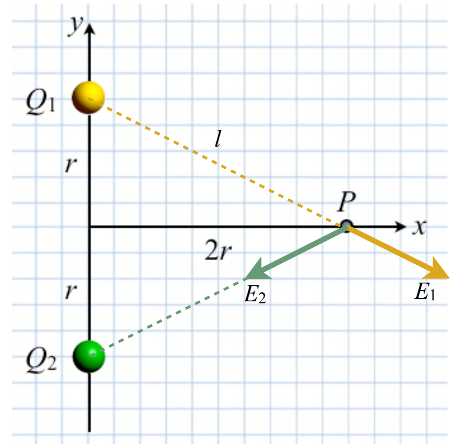
$$\sum F = F_q - T - mg = 0$$

$$T = F_q - mg = \frac{kq_1q_2}{r^2} - mg$$

$$T = \frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(3.5\times10^{-6}\text{C})(2.0\times10^{-6}\text{C})}{(0.30\text{m})^2} - (0.025\text{kg})(9.8\,\text{m/s}^2)$$

$$T = 0.455\text{N}$$

33. Two point charges are positioned as shown on the right. Fixed charge $Q_1 = +6.0$ nC. The fixed charge $Q_2 = -3.0$nC. The distance $r = 0.10$ m. (**Hint:** the angle that line PQ_1 makes with the x-axis is $tan^{-1}(r/2r) = tan^{-1}(1/2) = 26.6°$)



A) (5 points) Sketch the electric field vectors at point P due to the fixed charges. Be very careful with the vector directions.

The electric field vectors will point in the same direction as the force on a positive test charge placed at point P due to each of the fixed charges Q_1 and Q_2.

B) (5 points) Find the net electric field acting at P. Express your answer in the form of the vector components E_x and E_y. Be careful with your signs!!

$$r^2+(2r)^2=l^2 \implies l^2=5r^2=5(0.10\text{m})^2$$

$$E_{1x}=+\frac{kQ_1}{l^2}\cos26.6° = \frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(6\times10^{-9}\text{C})}{5(0.10\text{m})^2}\cos26.6° = +966\text{N/C}$$

$$E_{1y}=-\frac{kQ_1}{l^2}\sin26.6° = -\frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(6\times10^{-9}\text{C})}{5(0.10\text{m})^2}\sin26.6° = -484\text{N/C}$$

$$E_{2x}=-\frac{kQ_2}{l^2}\cos26.6° = -\frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(3\times10^{-9}\text{C})}{5(0.10\text{m})^2}\cos26.6° = -483\text{N/C}$$

$$E_{2y}=-\frac{kQ_2}{l^2}\sin26.6° = -\frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(3\times10^{-9}\text{C})}{5(0.10\text{m})^2}\sin26.6° = -242\text{N/C}$$

$$\sum E_x = E_{1x}+E_{2x} = +966-483 \implies E_x=+483\text{N/C}$$

$$\sum E_y = E_{1y}+E_{2y} = -484-242 \implies E_y=-725\text{N/C}$$

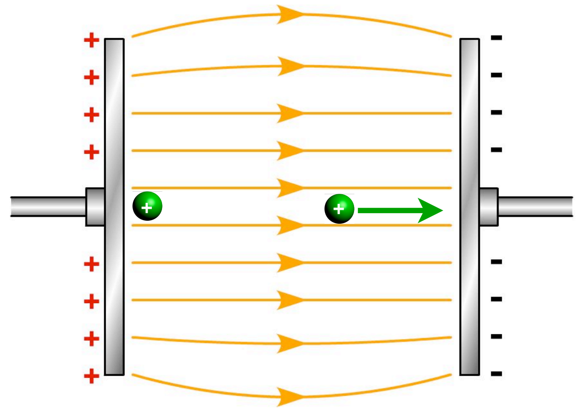
C) (5 points) What is the value of the electric potential V at point P?

$$l = \sqrt{5r^2} = \sqrt{5(0.10\text{m})^2} = 0.224\text{m}$$

$$V_1=\frac{kQ_1}{l}=\frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(+6\times10^{-9}\text{C})}{(0.224\text{m})}=+241\text{V}$$

$$V_2=-\frac{kQ_2}{l}=\frac{(9\times10^9\text{N}\cdot\text{m}^2/\text{C}^2)(-3\times10^{-9}\text{C})}{(0.224\text{m})}=-121\text{V}$$

$$V=V_1+V_2=+241-121=+120\text{V}$$



34. Two parallel plates having the same area ($A = 0.05\text{m}^2$) carry equal amounts of opposite charge, $Q = 4\times10^{-12}\text{C}$. The plates are separated by distance $x = 0.20\text{m}$. A particle having a mass $m = 2.0\times10^{-5}\text{kg}$ and charge $q = +2.0\mu\text{C}$ is released from rest in the uniform field created by these charged plates.

A) (5 points) Calculate the magnitude of the electric field E between the plates.

$$E=4\pi k\frac{Q}{A}=\frac{4\pi(9\times10^{9}\text{N}\cdot\text{m}^2/\text{C}^2)(4\times10^{-12}\text{C})}{(0.05\text{m}^2)}=9.05\text{N/C}$$

B) (5 points) Use Newton #2 to determine the acceleration of the particle.

$$F=qE=ma \implies a=\frac{qE}{m}$$

$$a=\frac{(4\times10^{-12}\text{C})(9.05\text{N/C})}{(2\times10^{-5}\text{kg})}=0.905\text{m/s}^2$$

C) (5 points) Use kinematics to determine the speed of the particle at the instant just before it slams into the negative plate.

$$v^2=v_o^2+2ax \implies v=\sqrt{2ax}$$

$$v=\sqrt{2(0.905\text{m/s}^2)(0.20\text{m})}=0.602\text{m/s}$$

D) (5 points) Calculate the potential difference, or voltage, between the two plates.

$$V=Ed=(9.05\text{N/C})(0.20\text{m})=1.81\text{V}$$

Formula Sheet for Chapters 14–15

Right Triangle Trigonometry:

$$\sin\theta = \frac{opposite}{hypotenuse}$$

$$\cos\theta = \frac{adjacent}{hypotenuse}$$

$$\tan\theta = \frac{opposite}{adjacent}$$

Pythagorean Theorem

$$(opposite)^2 + (adjacent)^2 = (hypotenuse)^2$$

Quadratic Formula:

$$ax^2 + bx + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Weight: $\vec{W} = m\vec{g}$

Kinematic Equations:

$$x = x_o + v_o t + \tfrac{1}{2}at^2$$

$$v = v_o + at$$

$$v^2 = v_o^2 + 2a(x - x_o)$$

Newton # 2:

$$\Sigma\vec{F} = m\vec{a}$$

$$\Sigma F_x = ma_x$$

$$\Sigma F_y = ma_y$$

proton: $m = 1.67 \times 10^{-27}\,\mathrm{kg}$ $\quad q = +1.6 \times 10^{-19}\,\mathrm{C}$

electron: $m = 9.1 \times 10^{-31}\,\mathrm{kg}$ $\quad e^- = -1.6 \times 10^{-19}\,\mathrm{C}$

Coulomb's Law: $F = k\frac{q_1 q_2}{r^2}$ $\quad \vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$

$$k = 9 \times 10^9 \,\frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$$

Work on Point Charges: $W = kqQ\left(\frac{1}{r_f} - \frac{1}{r_i}\right)$

Work to Assemble Point Charges From ∞: $U_{12} = \frac{kq_1q_2}{r_{12}}$

Gravitational Potential Energy: $U_g = mgh$

Electrical Potential Energy: $U = k\frac{q_1 q_2}{r}$

$$U = (qE)d$$

Electric Field: $\vec{F} = q\vec{E}$

Point Charge: $E = k\frac{Q}{r^2}$ $\quad \vec{E} = k\frac{Q}{r^2}\hat{r}$

Parallel Plates: $E = \frac{4\pi kQ}{A}$

Potential Difference: $\Delta V = \frac{\Delta U}{q} = \frac{W}{q}$

Point Charge: $V = \frac{kQ}{r}$

$$\Delta V = V_B - V_A \qquad \Delta V = \frac{kQ}{r_B} - \frac{kQ}{r_A}$$

Parallel Plates: $\Delta V = \frac{W}{q} = \frac{(qE)d}{q} = Ed$