

# Physics 111

## Exam #1

January 31, 2024

Name \_\_\_\_\_

Please read and follow these instructions carefully:

- Read all problems carefully before attempting to solve them.
- Your work must be legible, and the organization clear.
- You must show all work, including correct vector notation.
- You will not receive full credit for correct answers without adequate explanations.
- You will not receive full credit if incorrect work or explanations are mixed in with correct work. So, erase or cross out anything you don't want graded.
- Make explanations complete but brief. Do not write a lot of prose.
- Include diagrams.
- Show what goes into a calculation, not just the final number. For example,  
 $|\vec{p}| \approx m|\vec{v}| = (5\text{kg}) \times (2\frac{\text{m}}{\text{s}}) = 10\frac{\text{kg}\cdot\text{m}}{\text{s}}$
- Give standard SI units with your results unless specifically asked for a certain unit.
- Unless specifically asked to derive a result, you may start with the formulas given on the formula sheet including equations corresponding to the fundamental concepts.
- Go for partial credit. If you cannot do some portion of a problem, invent a symbol and/or value for the quantity you can't calculate (explain that you are doing this), and use it to do the rest of the problem.
- Each free-response part is worth 6 points.

Problem #1	/24
Problem #2	/24
Problem #3	/24
Total	/72

*I affirm that I have carried out my academic endeavors with full academic honesty.*

\_\_\_\_\_

1. Three point-charges are assembled along the x-axis with point-charge  $q_1 = +9\mu\text{C}$  located at  $(x_1, y_1) = (-5, 0)\text{cm}$ , point-charge  $q_2 = -3\mu\text{C}$  at  $(x_2, y_2) = (0, 0)\text{cm}$ , and point-charge  $q_3 = +2\mu\text{C}$  located at  $(x_3, y_3) = (+7, 0)\text{cm}$ .

- a. Assuming that each charge is brought in one at a time from very far away and placed in their final respective positions, how much work did it take to assemble the collection of point charges?

To place  $q_1$ :  $W_1 = 0$

To place  $q_2$ :  $W_2 = -q_2\Delta V_1 = -q_2 \left[ \frac{kq_1}{r_{12f}} - \frac{kq_1}{r_{12i}} \right]$

$$W_2 = -(-3 \times 10^{-6}\text{C}) \left[ \frac{9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2} \times 9 \times 10^{-6}\text{C}}{0.05\text{m}} - 0 \right] = 4.86\text{J}$$

To place  $q_3$ :  $W_3 = -q_3\Delta V_1 - q_3\Delta V_2 = -q_3 \left[ \frac{kq_1}{r_{31f}} - \frac{kq_1}{r_{31i}} \right] - q_3 \left[ \frac{kq_2}{r_{32f}} - \frac{kq_2}{r_{32i}} \right]$

$$W_3 = -(2 \times 10^{-6}\text{C}) \left[ \frac{9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2} \times 9 \times 10^{-6}\text{C}}{0.12\text{m}} - 0 \right] - (2 \times 10^{-6}\text{C}) \left[ \frac{9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2} \times (-3 \times 10^{-6}\text{C})}{0.07\text{m}} - 0 \right] = -0.58\text{J}$$

The net work:  $W_{net} = W_1 + W_2 + W_3 = 0\text{J} + 4.86\text{J} - 0.58\text{J} = 4.28\text{J}$

- b. What is the net electric force on point-charge  $q_1$  due to point-charges  $q_2$  and  $q_3$ ?

In the x-direction:

$$F_{net,1} = -F_{13} + F_{12} = \frac{kq_1q_3}{r_{13}^2} - \frac{kq_1q_2}{r_{12}^2} =$$

$$F_{net,2} = 9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2} \times 9 \times 10^{-6}\text{C} \left[ -\frac{2 \times 10^{-6}\text{C}}{(0.12\text{m})^2} + \frac{3 \times 10^{-6}\text{C}}{(0.05\text{m})^2} \right]$$

$F_{net,2} = 85.95\text{N}$  or  $86\text{N}$  in the positive x-direction.

- c. What is the net electric field at the origin,  $(x, y) = (0, 0)$ , due to  $q_1$  and  $q_3$ ?

$$E_p = E_{p,q_1} - E_{p,q_2} = \frac{kq_1}{r_{1p}^2} - \frac{kq_2}{r_{2p}^2} = 9 \times 10^9 \frac{Nm^2}{c^2} \left[ \frac{9 \times 10^{-6}C}{(0.05m)^2} - \frac{2 \times 10^{-6}C}{(0.07m)^2} \right]$$

$$E_p = 2.9 \times 10^7 \frac{N}{C} \text{ or } 2.9 \times 10^7 \frac{N}{C} \text{ in the positive x-direction.}$$

Or

$$F_{net,2} = F_{23} - F_{21} = \frac{kq_2q_3}{r_{23}^2} - \frac{kq_2q_1}{r_{21}^2} =$$

$$F_{net,2} = 9 \times 10^9 \frac{Nm^2}{c^2} \times 3 \times 10^{-6}C \left[ \frac{2 \times 10^{-6}C}{(0.07m)^2} - \frac{9 \times 10^{-6}C}{(0.05m)^2} \right]$$

$F_{net,2} = -86.2N$  or  $86.2N$  in the negative x-direction. And, since  $\vec{F}_{net,2} = q_2 \vec{E}_{net,2} \rightarrow \vec{E}_{net,2} = \frac{\vec{F}_{net,2}}{q_2} \rightarrow \vec{E}_{net,2} = \frac{-86.2N}{-3 \times 10^{-6}C} = 2.9 \times 10^7 \frac{N}{C}$  or  $2.9 \times 10^7 \frac{N}{C}$  in the positive x-direction.

- d. Suppose that point-charge  $q_2$  were released from rest. What will the speed of point-charge  $q_2$  be when it is at a distance of  $2cm$  from point-charge  $q_2$ ? Assume that the mass of point-charge  $q_2$  is  $0.5kg$ .

$$W = -q_2[\Delta V_1 + \Delta V_3] = \Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = \frac{1}{2}mv_f^2$$

$$W = -q_2 \left[ \left( \frac{kq_1}{r_{21f}} - \frac{kq_1}{r_{21i}} \right) + \left( \frac{kq_3}{r_{32f}} - \frac{kq_3}{r_{32i}} \right) \right] = \frac{1}{2}mv_f^2$$

$$W$$

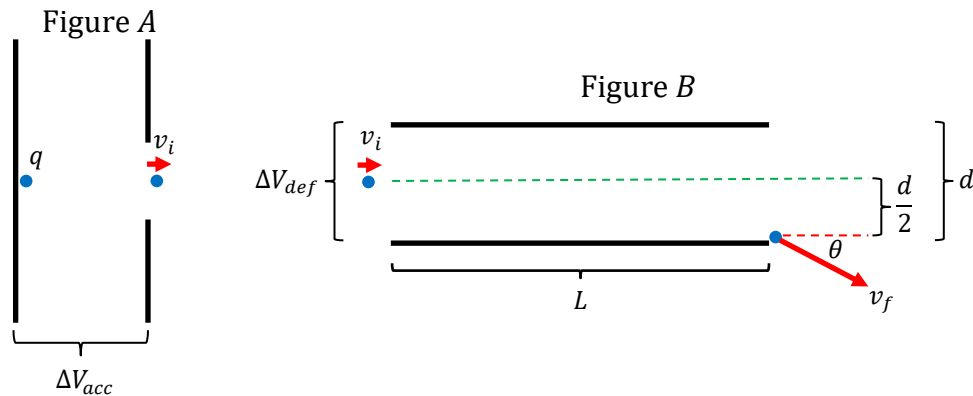
$$= -9 \times 10^9 \frac{Nm^2}{c^2}$$

$$\times (-3 \times 10^{-6}C) \left[ \left( \frac{9 \times 10^{-6}C}{0.02m} - \frac{9 \times 10^{-6}C}{0.05m} \right) + \left( \frac{2 \times 10^{-6}C}{0.10m} - \frac{2 \times 10^{-6}C}{0.07m} \right) \right]$$

$$W = 7.39 - 0.23J = 7.06J = \frac{1}{2}mv_f^2 \rightarrow v_f = \sqrt{\frac{2W}{m}} = \sqrt{\frac{2 \times 7.06J}{0.5kg}} = 5.3 \frac{m}{s}$$

2. As shown in Figure A below, a particle accelerator is used to accelerate a positive point-charge  $q = 12e$  and mass  $m = 1.66 \times 10^{-26} kg$  from rest near the left plate of the accelerator, through a potential difference  $\Delta V_{acc}$ . The point-charge exits through a hole in the right plate with a speed  $v_i$ . The positive point-charge is then incident at the midpoint between two horizontal plates separated by a distance of  $d = 2.4m$  as shown in Figure B. The positive point-charge travels a horizontal distance  $L$  between the plates and exits the system with a speed  $v_f = 5 \times 10^6 \frac{m}{s}$  directed at an angle  $\theta = 30^\circ$  below the horizontal.

Note: There was a typo in the problem. The final speed should have been  $5 \times 10^6 \frac{m}{s}$ , not  $5 \times 10^{-6} \frac{m}{s}$ . This didn't affect anyone's score on the problem. I graded the problem using  $5 \times 10^{-6} \frac{m}{s}$ .



- a. If the potential difference across the horizontal plates is  $\Delta V_{def} = 56000V$ , what is the magnitude and direction of the electric field between the horizontal plates and explain which plate (upper or lower) is at the higher electric potential?

The positive charge accelerates down (in the negative y-direction); thus, the electric field must point vertically down since positive charges accelerate in the direction of the electric field. And, electric fields point along decreasing electric potentials, so the upper plate must be at the higher electric potential.

$$E = -\frac{\Delta V_{def}}{\Delta y} = -\left[\frac{(0V - 56000V)}{(0m - 2.8m)}\right] = -20000 \frac{V}{m}$$

Or the electric field has magnitude  $20000 \frac{V}{m}$  vertically down.

- b. If the point-charge was accelerated over a vertical distance of  $\frac{d}{2}$ , how long was the point-charge interacting with the electric field?

$$v_{fy} = -v_f \sin \theta = -5 \times 10^{-6} \frac{m}{s} \sin 30 = -2.5 \times 10^{-6} \frac{m}{s}$$

$$v_{fy} = v_{iy} + a_y t \rightarrow t = \frac{v_{fy}}{a_y} = \frac{mv_{fy}}{qE} = \frac{1.66 \times 10^{-26} kg \times (-2.5 \times 10^{-6} \frac{m}{s})}{12 \times 1.6 \times 10^{-19} C \times (-20000 \frac{N}{C})}$$

$$t = 1.1 \times 10^{-6} s$$

or

$$y_f = y_i + v_{iy} t + \frac{1}{2} a_y t^2 \rightarrow t = \sqrt{\frac{2y_f}{a_y}} = \sqrt{-\frac{2m \frac{d}{2}}{qE}}$$

$$t = \sqrt{-\frac{1.66 \times 10^{-26} kg \times (-2.8m)}{12 \times 1.6 \times 10^{-19} C \times (-20000 \frac{N}{C})}} = 1.1 \times 10^{-6} s$$

- c. What is the length  $L$  of the horizontal plates?

$$v_{fx} = v_f \cos \theta = 5 \times 10^{-6} \frac{m}{s} \cos 30 = 4.33 \times 10^{-6} \frac{m}{s}$$

$$x_f = x_i + v_{ix} t + \frac{1}{2} a_x t^2 \rightarrow L = v_{ix} t = 4.33 \times 10^{-6} \frac{m}{s} \times 1.1 \times 10^{-6} s$$

$$L = 4.76m$$

- d. Through what potential difference  $\Delta V_{acc}$  was the point-charge initially accelerated?

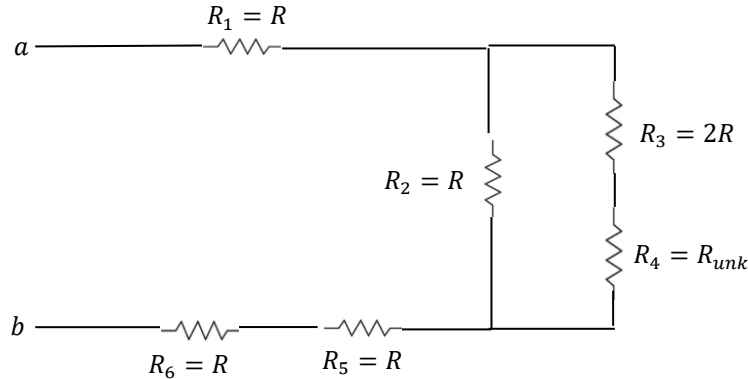
$$v_{fx} = v_{ix} + a_x t \rightarrow v_{fx} = v_{ix} = 4.33 \times 10^{-6} \frac{m}{s}$$

$$W = -q\Delta V_{acc} = \Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = \frac{1}{2}mv_f^2 \rightarrow \Delta V_{acc} = -\frac{mv_f^2}{2q}$$

$$\Delta V_{acc} = -\frac{1.66 \times 10^{-26} kg \left(4.33 \times 10^{-6} \frac{m}{s}\right)^2}{2 \times 12 \times 1.6 \times 10^{-19} C} = -8.1 \times 10^4 V$$

3. Consider the following part of a circuit shown in Figure C where several resistors are wired together between points  $a$  and  $b$ . Each resistor has a resistance  $R$  except for the unknown resistance  $R_{unk}$ .

Figure C



- a. If the equivalent resistance between points  $a$  and  $b$  needs to be  $R_{eq} = \frac{19}{5}R$ , what is the value of  $R_{unk}$  in terms of  $R$ ? Note, do not use any numerical value of any resistor given in the remainder of the problem to answer this part. Your answer should be of the form  $R_{unk} = CR$ , where the constant  $C$  is either a fraction (number less than 1) or a multiple (number greater than 1) of  $R$  and the answer to this question is not required to complete the remainder of the problem.

$$R_3 \text{ and } R_4 \text{ are in series: } R_{34} = R_3 + R_4 = 2R + R_{unk} = (2 + C)R$$

$$R_2 \text{ and } R_{34} \text{ are in parallel: } \frac{1}{R_{234}} = \frac{1}{R_2} + \frac{1}{R_{34}} = \frac{1}{R} + \frac{1}{(2+C)R} = \frac{(2+C)R + R}{R(2+C)R}$$

$$R_{234} = \frac{(2 + C)R^2}{3R + CR} = \frac{(2 + C)R}{3 + C}$$

$$R_1, R_{234}, R_5 \text{ and } R_6 \text{ are in series: } R_{eq} = R_{123456} = R_1 + R_{234} + R_5 + R_6$$

$$R_{eq} = \frac{19}{5}R = R + \frac{(2 + C)R}{3 + C} + R + R = 3R + \frac{(2 + C)R}{3 + C}$$

$$\rightarrow \frac{19}{5}R - 3R = \frac{4}{5}R = \frac{(2 + C)R}{3 + C}$$

$$\rightarrow 4(3 + C) = 5(2 + C) \rightarrow 12 + 4C = 10 + 5C \rightarrow C = 2$$

$$R_{unk} = 2R$$

- b. Suppose this network of resistors were wired to an uncharged  $30,000\mu F$  capacitor and a  $12V$  battery. At what time  $t$  does the potential difference across the capacitor  $V_C$  equal  $8V$  if  $R = 10,000\Omega$ ?

$$V = V_{max} \left( 1 - e^{-\frac{t}{R_{eq}C}} \right) \rightarrow t = -R_{eq}C \ln \left( 1 - \frac{V}{V_{max}} \right) = -\frac{19}{5} RC \ln \left( 1 - \frac{V}{V_{max}} \right)$$

$$t = -\frac{19}{5} \times 10000\Omega \times 30000 \times 10^{-6}F \ln \left( 1 - \frac{8V}{12V} \right) = 1252.4s$$

- c. At the time  $t$  determined in part b, what is the current  $I$  that is flowing in the circuit and what is the potential difference across the equivalent resistor,  $V_R$ ?

By conservation of energy,  $V = V_C + V_R \rightarrow V_R = V - V_C = 12V - 8V = 4V$

$$V_{Req} = IR_{eq} \rightarrow I = \frac{V_{Req}}{R_{eq}} = \frac{4V}{\frac{19}{5} \times 10000\Omega} = 1.1 \times 10^{-4}A = 0.11mA$$

$$\text{Or, } I = I_{max} e^{-\frac{t}{R_{eq}C}} = \frac{Q_{max}}{R_{eq}C} e^{-\frac{t}{R_{eq}C}} = \frac{CV_{max}}{R_{eq}C} e^{-\frac{t}{R_{eq}C}} = \frac{V_{max}}{R_{eq}} e^{-\frac{t}{R_{eq}C}}$$

$$I = \frac{12V}{\frac{19}{5} \times 10000\Omega} e^{-\frac{1252.4s}{\frac{19}{5} \times 10000\Omega \times 30000 \times 10^{-6}F}} = 1.1 \times 10^{-4}A = 0.11mA$$

$$\text{Then, } V_R = IR = 1.1 \times 10^{-4}A \times \frac{19}{5} \times 10000\Omega = 4V$$

- d. For the current  $I$  found in part c, what is the drift velocity of the charge carriers in the wire? Assume that the wires in the circuit are made from tungsten ( $W$ ) with a density  $\rho_W = 19250 \frac{kg}{m^3}$ , molecular mass  $M_W = 181 \frac{g}{mol}$ , have a radius  $r = 1mm$ , and that tungsten donates 2 charge carriers per tungsten atom.

$$I = neAv_d \rightarrow v_d = \frac{I}{neA}$$

$$v_d = \frac{1.1 \times 10^{-4}A}{1.26 \times 10^{29}m^{-3} \times 1.6 \times 10^{-19}C \times \pi(1 \times 10^{-3}m)^3} = 1.7 \times 10^{-9}A$$

$$v_d = 1.7nA$$

where,

$$n = \left( \frac{\rho_W N_A}{M_W} \right) \times \frac{\text{charge carriers}}{\text{atom}} = \frac{19250 \frac{kg}{m^3} \times 6.02 \times 10^{23} \frac{Watoms}{mol}}{0.181 \frac{kg}{mol}} \times 2atom^{-1}$$

$$n = 1.28 \times 10^{29}m^{-3}$$

## Physics 111 Formula Sheet

### Electrostatics

$$F = k \frac{q_1 q_2}{r^2}$$

$$\vec{F} = q\vec{E}; \quad E_{pc} = k \frac{q}{r^2}; \quad E_{plate} = \frac{q}{\epsilon_0 A}$$

$$E = -\frac{\Delta V}{\Delta x}$$

$$V_{pc} = k \frac{q}{r}$$

$$U_e = k \frac{q_1 q_2}{r} = qV$$

$$W = -q\Delta V = -\Delta U_e = \Delta K$$

### Electric Circuits - Capacitors

$$Q = CV; \quad C = \frac{\kappa \epsilon_0 A}{d}$$

$$C_{parallel} = \sum_{i=1}^N C_i$$

$$\frac{1}{C_{series}} = \sum_{i=1}^N \frac{1}{C_i}$$

$$Q_{charging}(t) = Q_{max} \left(1 - e^{-\frac{t}{\tau}}\right)$$

$$Q_{discharging}(t) = Q_{max} e^{-\frac{t}{\tau}}$$

$$I(t) = I_{max} e^{-\frac{t}{\tau}} = \frac{Q_{max}}{\tau} e^{-\frac{t}{\tau}}$$

$$\tau = RC$$

$$U_C = \frac{1}{2}qV = \frac{1}{2}CV^2 = \frac{Q^2}{2C}$$

### Light as a Wave

$$c = f\lambda$$

$$S(t) = \frac{\text{Energy}}{\text{time} \times \text{Area}} = c\epsilon_0 E^2(t) = c \frac{B^2(t)}{\mu_0}$$

$$I = S_{avg} = \frac{1}{2}c\epsilon_0 E_{max}^2 = c \frac{B_{max}^2}{2\mu_0}$$

$$P = \begin{cases} \frac{S}{c}; & \text{absorbed} \\ \frac{2S}{c}; & \text{reflected} \end{cases}$$

$$S = S_0 \cos^2 \theta$$

$$v = \frac{c}{n}$$

$$\theta_{incident} = \theta_{reflected}$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$P = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$M = \frac{d_i}{d_o}; \quad |M| = \frac{h_i}{h_o}$$

### Magnetism

$$\vec{F} = q\vec{v} \times \vec{B} \rightarrow F = qvB \sin \theta$$

$$\vec{F} = I\vec{L} \times \vec{B} \rightarrow F = ILB \sin \theta$$

$$V_{Hall} = wv_d B$$

$$B = \frac{\mu_0 I}{2\pi r}$$

$$\mathcal{E} = \Delta V = -N \frac{\Delta \phi_B}{\Delta t}$$

$$\phi_B = BA \cos \theta$$

### Electric Circuits - Resistors

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = neAv_d; \quad n = \frac{\rho N_A}{m}$$

$$V = IR$$

$$R = \frac{\rho L}{A}$$

$$R_{series} = \sum_{i=1}^N R_i$$

$$\frac{1}{R_{parallel}} = \sum_{i=1}^N \frac{1}{R_i}$$

$$P = \frac{\Delta E}{\Delta t} = IV = I^2 R = \frac{V^2}{R}$$

### Light as a Particle/Relativity

$$E = hf = \frac{hc}{\lambda}$$

$$K_{max} = hf - \phi$$

$$\Delta \lambda = \lambda' - \lambda = \frac{h}{mc} (1 - \cos \phi)$$

$$\frac{1}{E'} = \frac{1}{E} + \frac{(1 - \cos \phi)}{E_{rest}}; \quad E_{rest} = mc^2$$

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$p = \gamma mv$$

$$E_{total} = E_{rest} + K = \gamma mc^2$$

$$K = (\gamma - 1)mc^2$$

$$E_{total}^2 = p^2 c^2 + m^2 c^4$$



## Nuclear Physics

$$N = N_0 e^{-\lambda t}$$

$$m = m_0 e^{-\lambda t}$$

$$A = A_0 e^{-\lambda t}$$

$$A = \lambda N$$

$$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

## Constants

$$g = 9.8 \frac{m}{s^2}$$

$$1e = 1.6 \times 10^{-19} C$$

$$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \frac{Nm^2}{C^2}$$

$$\epsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}$$

$$1eV = 1.6 \times 10^{-19} J$$

$$\mu_0 = 4\pi \times 10^{-7} \frac{Tm}{A}$$

$$c = 3 \times 10^8 \frac{m}{s}$$

$$h = 6.63 \times 10^{-34} Js = 4.14 \times 10^{-15} eVs$$

$$N_A = 6.02 \times 10^{23}$$

$$1u = 1.66 \times 10^{-27} kg = 931.5 \frac{MeV}{c^2}$$

$$m_p = 1.67 \times 10^{-27} kg = 937.1 \frac{MeV}{c^2}$$

$$m_n = 1.69 \times 10^{-27} kg = 948.3 \frac{MeV}{c^2}$$

$$m_e = 9.11 \times 10^{-31} kg = 0.511 \frac{MeV}{c^2}$$

## Physics 110 Formulas

$$\vec{F} = m\vec{a}; \quad F_G = \frac{GM_1m_2}{r^2}; \quad F_s = -ky; \quad a_c = \frac{v^2}{r}$$

$$W = -\Delta U_g - \Delta U_s = \Delta K$$

$$U_g = mgy$$

$$U_s = \frac{1}{2}ky^2$$

$$K = \frac{1}{2}mv^2$$

$$\vec{r}_f = \vec{r}_i + \vec{v}_i t + \frac{1}{2}\vec{a}t^2$$

$$\vec{v}_f = \vec{v}_i + \vec{a}t$$

$$v_f^2 = v_i^2 + 2a_r \Delta r$$

## Common Metric Units

$$\text{nano (n)} = 10^{-9}$$

$$\text{micro } (\mu) = 10^{-6}$$

$$\text{milli (m)} = 10^{-3}$$

$$\text{centi (c)} = 10^{-2}$$

$$\text{kilo (k)} = 10^3$$

$$\text{mega (M)} = 10^6$$

## Geometry/Algebra

Circles:  $A = \pi r^2$   $C = 2\pi r = \pi$

Spheres:  $A = 4\pi r^2$   $V = \frac{4}{3}\pi r^3$

Triangles:  $A = \frac{1}{2}bh$

Quadratics:  $ax^2 + bx + c = 0 \rightarrow x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

# PERIODIC TABLE OF ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18																																											
1 H Hydrogen 1.008	2 He Helium 4.0026																																																											
3 Li Lithium 6.94	4 Be Beryllium 9.0122											5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180																																											
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.085	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948																																											
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798																																											
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29																																											
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanoids (Lanthanides)	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)																																											
87 Fr Francium (223)	88 Ra Radium (226)	89-103 Actinoids (Actinides)	104 Rf Rutherfordium (261)	105 Db Dubnium (268)	106 Sg Seaborgium (269)	107 Bh Bohrium (270)	108 Hs Hassium (277)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (290)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)																																											
For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.																																																												
<table border="1"> <thead> <tr> <th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th> </tr> </thead> <tbody> <tr> <td>57 La Lanthanum 138.91</td> <td>58 Ce Cerium 140.12</td> <td>59 Pr Praseodymium 140.91</td> <td>60 Nd Neodymium 144.24</td> <td>61 Pm Promethium (145)</td> <td>62 Sm Samarium 150.36</td> <td>63 Eu Europium 151.96</td> <td>64 Gd Gadolinium 157.25</td> <td>65 Tb Terbium 158.93</td> <td>66 Dy Dysprosium 162.50</td> <td>67 Ho Holmium 164.93</td> <td>68 Er Erbium 167.26</td> <td>69 Tm Thulium 168.93</td> <td>70 Yb Ytterbium 173.05</td> <td>71 Lu Lutetium 174.97</td> </tr> <tr> <td>89 Ac Actinium (227)</td> <td>90 Th Thorium 232.04</td> <td>91 Pa Protactinium 231.04</td> <td>92 U Uranium 238.03</td> <td>93 Np Neptunium (237)</td> <td>94 Pu Plutonium (244)</td> <td>95 Am Americium (243)</td> <td>96 Cm Curium (247)</td> <td>97 Bk Berkelium (247)</td> <td>98 Cf Californium (251)</td> <td>99 Es Einsteinium (252)</td> <td>100 Fm Fermium (257)</td> <td>101 Md Mendelevium (258)</td> <td>102 No Nobelium (259)</td> <td>103 Lr Lawrencium (260)</td> </tr> </tbody> </table>																		6	7	8	9	10	11	12	13	14	15	16	17	18	57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97	89 Ac Actinium (227)	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)
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