Physics 111

Exam #1

September 22, 2025

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, $|\vec{p}| \approx m|\vec{v}| = (5kg) \times (2\,\frac{m}{s}) = 10\,\frac{kg\cdot m}{s}$
- 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.

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1. Calcium chloride ($CaCl_2$) is an ionic salt. In aqueous solutions it separates into Ca^{+2} and Cl^- ions. These ions are essential for cellular functions. Consider building a molecule of calcium chloride by arranging the charges in a line according to chlorine – calcium – chlorine, with each calcium – chlorine ion separated by a distance $s = 0.295nm$.

   a. How much work (in electron volts) is done to build $CaCl_2$? Hints: The charges of the calcium and chlorine ions are $+2e$ and $-1e$ respectively and suppose that each charge is brought in from very far away and placed in their final locations.

   I'm going to build $CaCl_2$ by putting the calcium down first, then the left most chlorine, followed by the right most chlorine. The order of placement, of course, does not matter.

$$W_{Ca} = -q_{Ca}\Delta V = 0J$$

$$W_{L,Cl} = -q_{L,Cl}\Delta V_{Ca} = -q_{L,Cl}\left[\frac{kq_{Ca}}{r_{f,Ca-Cl}} - \frac{kq_{Ca}}{r_{i,Ca-Cl}}\right] = -(-e)\left[\frac{k(2e)}{s} - 0\right]$$

$$W_{L,Cl} = \frac{9\times 10^9\frac{Nm^2}{C^2}\times 2\times(1.6\times 10^{-19}C)^2}{0.295\times 10^{-9}m} = 1.56\times 10^{-18}J$$

$$W_{R,Cl} = -q_{R,Cl}\Delta V_{Ca} - q_{R,Cl}\Delta V_{L,Cl}$$

$$W_{R,Cl} = -q_{R,Cl}\left[\frac{kq_{Ca}}{r_{f,Ca-Cl}} - \frac{kq_{Ca}}{r_{i,Ca-Cl}}\right] - q_{R,Cl}\left[\frac{kq_{CL,Cl}}{r_{f,Cl-Cl}} - \frac{kq_{L,Cl}}{r_{i,Cl-Cl}}\right]$$

$$W_{R,Cl} = -(-e)\left[\frac{k(2e)}{s} - 0\right] - (-e)\left[\frac{k(-e)}{2s} - 0\right]$$

$$W_{R,Cl} = \frac{9\times 10^9\frac{Nm^2}{C^2}\times 2\times(1.6\times 10^{-19}C)^2}{0.295\times 10^{-9}m} - \frac{9\times 10^9\frac{Nm^2}{C^2}(1.6\times 10^{-19}C)^2}{2\times 0.295\times 10^{-9}m}$$

$$W_{R,Cl} = 1.17\times 10^{-18}J$$

$$W_{net} = W_{Ca} + W_{L,Cl} + W_{R,Cl} = 2.73\times 10^{-18}J \times \frac{1eV}{1.6\times 10^{-19}J} = 17.1eV$$

   b. What is the electric potential energy (in eV) stored in the system? In addition to calculating or stating a value, explain the significance of the sign of the electric potential energy.

   $W_{net} = -\Delta U_e \rightarrow \Delta U_e = -17.1eV$.
   The electric potential energy is negative. This is a reflection of a bound (or stable) state. To unbind the $CaCl_2$, we would need to input energy into the system.

c. What is the net electric field (magnitude and direction) at the right most chlorine ion due to the left most chlorine ion and the calcium ion?

Taking to the right as the positive x-direction, we have:

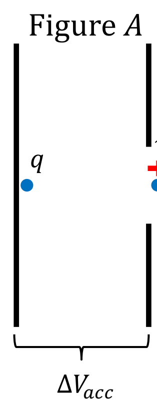
$$E_{net} = +E_{Ca} - E_{Cl} = \frac{kq_{Ca}}{r^2_{Ca-Cl}} - \frac{kq_{Cl}}{r^2_{Cl-Cl}} = \frac{9 \times 10^9 \frac{Nm^2}{C^2} \times 1.6 \times 10^{-19} C}{(0.295 \times 10^{-9} m)^2}\left(2 - \frac{1}{4}\right)$$

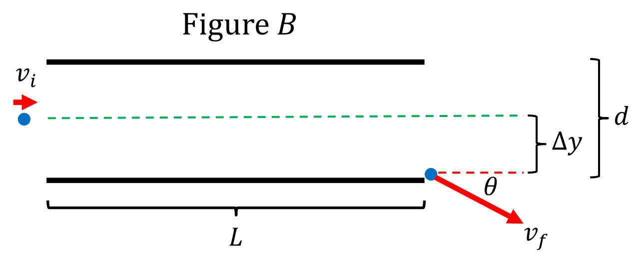
$E_{net} = 2.9 \times 10^{10} \frac{N}{C}$ in the positive x-direction.

d. What is the net force on the right most chlorine ion due to the left most chlorine ion and the calcium ion?

$F_{L,Cl} = q_{L,Cl} E_{net} = 1.6 \times 10^{-19} C \times 2.9 \times 10^{10} \frac{N}{C} = 4.6 \times 10^{-9} N$ in magnitude and the force points in the negative x-direction (opposite to the direction of the electric field since the charge of the chlorine is negative).

2. Suppose an electron is accelerated horizontally from rest using a set of vertical parallel plates. The electron is accelerated from rest at the left vertical plate through a potential difference and the electron emerges from a small hole in the right vertical plate as shown in Figure A below. After the electron emerges from the small hole in the right plate it passes between a set of parallel horizontal plates shown if Figure B below. The electron emerges from these horizontal plates with a speed $v = 9 \times 10^6 \frac{m}{s}$ directed at an angle $\theta = 60^0$ below the horizontal, as shown below.





a. Through what potential difference ΔV_{acc} was the electron accelerated in Figure A?

Taking to the right and vertically up as the positive x- and y-directions respectively we have that since there is no horizontal force, the horizontal motion is a constant. Therefore,

$$v_{fx} = v_{ix} = v_i = v_f \cos\theta = 9 \times 10^6 \frac{m}{s} \cos 60 = 4.5 \times 10^6 \frac{m}{s}$$

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

$$\Delta V_{acc} = -\frac{mv_f^2}{2q} = -\frac{9.11 \times 10^{-31} kg \times \left(4.5 \times 10^6 \frac{m}{s}\right)^2}{2 \times (-1.6 \times 10^{-19} C)} = 57.7V$$

b. If the electron was accelerated over a vertical distance of $\Delta y = -12cm$, What is the magnitude and direction of the electric field in the horizontal set of plates in Figure B?

$$v_{fy} = v_f \sin\theta = 9 \times 10^6 \frac{m}{s} \sin 60 = 7.8 \times 10^6 \frac{m}{s}$$

$$v_{fy}^2 = v_{iy}^2 + 2a_y\Delta y = 2\left(\frac{qE}{m}\right)\Delta y \rightarrow E = \frac{mv_{fy}^2}{2q\Delta y}$$

$$E = \frac{9.11 \times 10^{-31} kg \times \left(7.8 \times 10^6 \frac{m}{s}\right)^2}{2(-1.6 \times 10^{-19} C)(-0.12m)} = 1441 \frac{N}{C}$$

Since this is positive, the electric field points in the positive y-direction.

c. How long does the electron spend crossing the horizontal set of plates and what is the length L of the horizontal plates in Figure B?

$$y_f = y_i + v_{iy}t + \tfrac{1}{2}a_y t^2 \rightarrow \Delta y = \left(\frac{qE}{2m}\right)t^2 \rightarrow t = \sqrt{\frac{2m\Delta y}{qE}}$$

$$t = \sqrt{\frac{2 \times 9.11 \times 10^{-31}kg \times (-0.12m)}{\left(-1.6 \times 10^{-19}C\right) \times 1441\frac{N}{C}}} = 3.1 \times 10^{-8}s$$

$$x_f = x_i + v_{ix}t + \tfrac{1}{2}a_x t^2 \rightarrow L = v_{ix}t = 4.5 \times 10^6\frac{m}{s} \times 3.1 \times 10^{-8}s = 0.138m = 14cm$$

d. If the horizontal set of plates were square and separated by a distance $d = 30cm$, which plate is at the higher electric potential and what is the potential difference across the horizontal set of plates? Justify our choice of which plate is at the higher electric potential with a sentence or two.

Since the electric field points along decreasing electric potentials, and since the electric field points in the positive y-direction, the lower plate must be at the higher electric potential and the upper plate at the lower electric potential. This can also be argued by noting that the electron's motion is down. Thus, the lower plate must have a positive charge and the upper plate a negative charge. The electric field points from the positive lower plate to the negative upper plate along decreasing electric potentials.

$$E = -\frac{\Delta V}{\Delta y} \rightarrow \Delta V = -Ed = -1441\frac{N}{C} \times 0.3m = 432.3V$$

3. An air-filled parallel plate capacitor is constructed out of two parallel circular metal plates of radius $r = 1m$ separated by a distance of $d = 10cm$.

   a. What is the capacitance of the system and how much charge could be stored in the capacitor when it is fully charged if the capacitor was connected to a $1000V$ battery?

$$C = \frac{\kappa\epsilon_0 A}{d} = \frac{1 \times 8.85 \times 10^{-12}\frac{C^2}{Nm^2} \times \pi(1m)^2}{0.1m} = 2.8 \times 10^{-10}F$$

$$Q = CV = 2.8 \times 10^{-10}F \times 1000V = 2.8 \times 10^{-7}C$$

   b. Assuming that the capacitor is fully charged, what is the magnitude of the electric field between the plates of the capacitor?

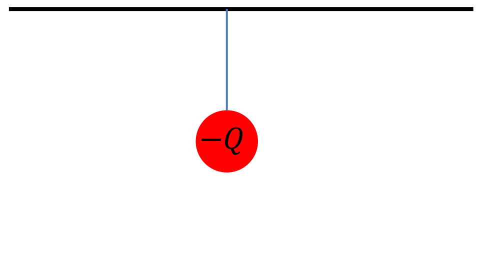
$$E = \frac{Q}{\epsilon_0 A} = \frac{2.8 \times 10^{-7}C}{8.85 \times 10^{-12}\frac{C^2}{Nm^2} \times \pi(1m)^2} = 1 \times 10^4\frac{N}{C}$$

Or,

$$|E| = \left|-\frac{\Delta V}{\Delta y}\right| = \frac{1000V}{0.1m} = 1 \times 10^4\frac{V}{m}$$

c. Suppose we orient the capacitor as shown below in Figure C. From the upper plate we suspend a conducting sphere of mass $m = 0.8kg$ at the end of an insulating string. A charge $-Q$ is then placed on the conducting sphere. The system is in equilibrium and when the system is in equilibrium, the tension measured in the string has a value $F_T = 4.6N$. What is the magnitude of the charge that was placed on the conducting sphere?

Figure C



Assuming up is the positive y-direction. The tension points in the positive y-direction and the weight in the negative y-direction. Let's assume too that the electric force points in the positive. If the sum of the sum of the tension and weight is negative then the electric force must point in the positive y-direction. If the sum of the sum of the tension and weight points is positive then the electric force must in the negative y-direction.

$$F_T - F_W + F_e = ma_y = 0 \rightarrow F_T - F_W + F_e = 4.6N - \left(0.8kg \times 9.8\tfrac{m}{s^2}\right) + F_e = 0$$

$$-3.24N + F_e = 0 \rightarrow F_e = +3.24N$$

$$F_e = qE \rightarrow Q = \frac{F_e}{E} = \frac{3.24N}{1 \times 10^4 \frac{N}{C}} = 3.24 \times 10^{-4} C$$

d. For the situation in part c, fully explain what is the direction of the electric field between the plates and which plate (upper or lower) has the positive charge on it.

Using the explanation in part c, since the electric force points in the positive y-direction and the charge is negative, the charge feels a force opposite to the direction of the electric field. Thus, the electric field must point vertically down. To achieve this, the upper plate must be positively charged and the lower plate negatively charged.

Physics 111 Formula Sheet

Electrostatics

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

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

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

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

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

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

Electric Circuits - Capacitors

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

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

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

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

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

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

$\tau = RC$

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

Light as a Wave

$c = f\lambda$

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

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

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

$S = S_0 \cos^2 \theta$

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

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

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

$P = \frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_i}$

$M = \frac{d_i}{d_0}$; $|M| = \frac{h_i}{h_0}$

Magnetism

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

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

$V_{Hall} = wv_d B$

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

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

$\phi_B = BA\cos\theta$

Electric Circuits - Resistors

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

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

$V = IR$

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

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

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

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

Light as a Particle/Relativity

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

$K_{max} = hf - \phi$

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

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

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

$p = \gamma mv$

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

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

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

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

$\vec{F} = m\vec{a}$; $F_G = \frac{GM_1 m_2}{r^2}$; $F_s = -ky$; $a_c = \frac{v^2}{r}$

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

$U_g = mgy$

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

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

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

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

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

Common Metric Units

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

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

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

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

$kilo\ (k) = 10^3$

$mega\ (M) = 10^6$

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

Atomic # / Symbol / Name / Weight

C Solid; Hg Liquid; H Gas; Rf Unknown

Metals: Alkali metals, Alkaline earth metals, Lanthanoids (Lanthanides), Actinoids (Actinides), Transition metals, Post-transition metals; Metalloids; Nonmetals: Other nonmetals, Noble gases

Pnictogens, Chalcogens, Halogens

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.008																	2 He Helium 4.0026
2	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
3	11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminium 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
4	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
5	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
6	55 Cs Caesium 132.91	56 Ba Barium 137.33	57–71	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)
7	87 Fr Francium (223)	88 Ra Radium (226)	89–103	104 Rf Rutherfordium (267)	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.

6	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
7	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 (266)

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