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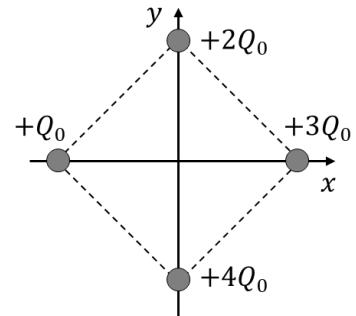
Clearly fill out this cover page and the top portion of the provided bubble sheet with the necessary information.

Do not open the exam until told to do so.
When prompted, clearly print the information required at the top of each page of this exam booklet.

You can remove the equation sheet(s). Otherwise, keep the exam booklet intact. You will have 60 minutes to complete the examination.

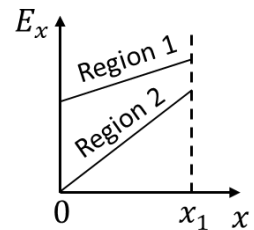
I. Lecture multiple choice (45 points – 9 questions)

- 1) (5 pts) Four point particles are fixed at the corners of a $0.010\text{m} \times 0.010\text{m}$ square, as shown. The electric potential at infinity is zero and $Q_0 = 1.2 \times 10^{-9}\text{C}$. Find the electric potential at the origin $(x, y) = (0, 0)$.



- A. $V(0,0) = 3.1 \times 10^3 \text{ V}$
- B. $V(0,0) = 4.3 \times 10^3 \text{ V}$
- C. $V(0,0) = 6.1 \times 10^3 \text{ V}$
- D. $V(0,0) = 1.1 \times 10^4 \text{ V}$
- E. $V(0,0) = 1.5 \times 10^4 \text{ V}$

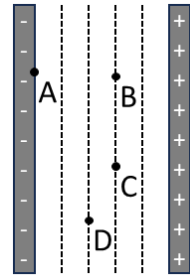
- 2) (5 pts) The electric field is measured in two regions of space, 1 and 2. For both regions the graph on the right shows the x component of the electric field, E_x , as a function of x from 0 to x_1 . Consider the absolute value of the change in electric **potential** between $x = 0$ and x_1 for region 1, $|\Delta V_1|$, and region 2, $|\Delta V_2|$. Which one of the following statements is correct?



- A. $|\Delta V_1| < |\Delta V_2|$ because E_x changes at a greater rate with respect to x in region 2.
- B. $|\Delta V_1| < |\Delta V_2|$ because E_x is smaller at the origin in region 2.
- C. $|\Delta V_1| > |\Delta V_2|$ because E_x changes at a smaller rate with respect to x in region 1.
- D. $|\Delta V_1| > |\Delta V_2|$ because the area under the E_x versus x curve between $x = 0$ and x_1 is greater in region 1.
- E. We can't compare $|\Delta V_1|$ and $|\Delta V_2|$ unless we know the values of the field and the positions

- 3) (5 pts) Consider the following two scenarios where a single capacitor is connected to a single battery: capacitor A is connected to battery A, and capacitor B is connected to battery B. The capacitance of capacitor A is smaller than the capacitance of capacitor B by a factor of 0.6. The emf of battery A is greater than the emf of battery B by a factor of 1.2. Compare the energy stored in capacitor A, U_A , to the energy stored in capacitor B, U_B . Which one of the following statements is correct?
- $U_A > U_B$ because battery A has a greater emf.
 - $U_A < U_B$ because capacitor B has a greater capacitance.
 - $U_A = U_B$ because the greater emf of battery A cancels out the smaller capacitance of capacitor A.
 - $U_A > U_B$ because the greater emf of battery A more than compensates for smaller capacitance of capacitor A.
 - $U_A < U_B$ because the greater capacitance of capacitor B more than compensates for the smaller emf of capacitor B.

- 4) (5 pts) A particle in a parallel plate capacitor is moved from positions A to B to C to D. The equipotential lines are shown on the diagram. Which of the following correctly represents the electric potential difference between points A and D, ΔV_{AD} ? Note that the notation ΔV_{AD} represents $V_D - V_A$.

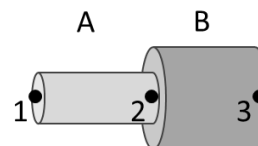


- $\Delta V_{AD} = \Delta V_{AB} + \Delta V_{BC} - \Delta V_{CD}$
- $\Delta V_{AD} = \Delta V_{AB} - \Delta V_{BC} - \Delta V_{CD}$
- $\Delta V_{AD} = \Delta V_{AB} + \Delta V_{CD}$
- $\Delta V_{AD} = \Delta V_{AB} - \Delta V_{CD}$
- The correct choice would depend on the sign of the charge that is being moved.

- 5) (5 pts) A parallel-plate capacitor is connected to a battery, fully charged, and then the battery is **disconnected**. A dielectric is then inserted between the plates of the capacitor while the separation distance of the plates remains fixed. Comparing the initial state without the dielectric to the state after the dielectric is inserted, which one of the following correctly describes the resulting changes, if any, to the absolute value of the charge on the plates, Q_o , and the absolute value potential difference across the capacitor, V_{cap} ?
- Both Q_o and V_{cap} stay the same.
 - Both Q_o and V_{cap} decrease.
 - Q_o increases and V_{cap} stays the same.
 - Q_o decreases and V_{cap} increases.
 - Q_o stays the same and V_{cap} decreases.

- 6) (5 pts) A wire of cross-sectional area $A = 4.5 \times 10^{-6} \text{ m}^2$, length $L = 0.30 \text{ m}$, and resistivity $\rho = 3.4 \times 10^{-8} \Omega \cdot \text{m}$ carries current $I = 12 \text{ A}$ along it. What is the potential difference between the ends of the wire?
- A. $\Delta V = 1.6 \times 10^{-5} \text{ V}$
 - B. $\Delta V = 2.7 \times 10^{-2} \text{ V}$
 - C. $\Delta V = 1.0 \times 10^{-4} \text{ V}$
 - D. $\Delta V = 37 \text{ V}$
 - E. None of the above

- 7) (5 pts) Two wires, A and B, have equal length but with different radii, and are made of metals with different resistivities. Wires A and B are connected as shown, and one side of a battery is connected to point 1 (the left of wire A), and the other side of the battery is connected to point 3 (the right of wire B). Point 2 is where wires A and B are connected. The electrical potential difference across wire A, ΔV_{12} , is greater than that across wire B, ΔV_{23} . Consider the following statements comparing the current densities, J , currents, I , and electric fields, E , in wires A and B:

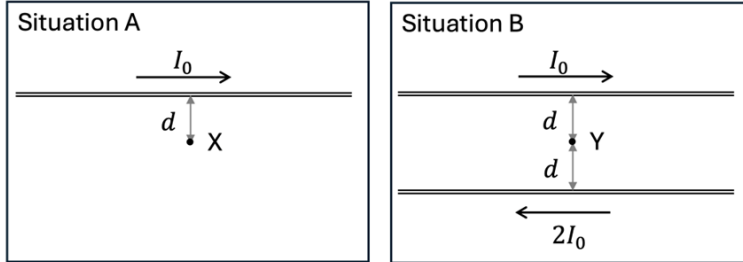


- i. $J_A = J_B$
- ii. $I_A = I_B$
- iii. $E_A = E_B$

Which of these statements are correct?

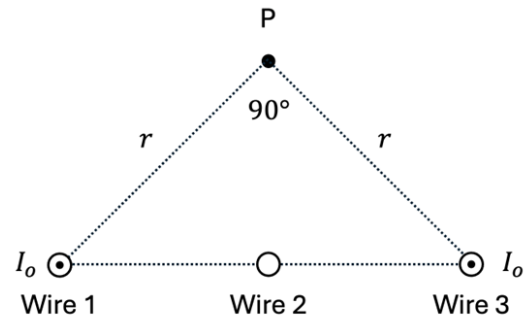
- A. All of them.
- B. None of them.
- C. Only ii.
- D. i. and ii.
- E. i. and iii.

- 8) (5 pts) Consider two different configurations of wires. In configuration A, a long thin wire carries current I_0 . At point X, a distance d away from the wire, the magnetic field is B_0 directed into the page. Configuration B is identical to configuration A, except a second wire carries current $2I_0$ in the opposite direction and point Y is a distance d away from each wire, as shown. What is the magnetic field at point Y in configuration 2?



- A. 0
 B. B_0 directed out of the page
 C. B_0 directed into the page
 D. $3B_0$ directed into the page
 E. None of the above.

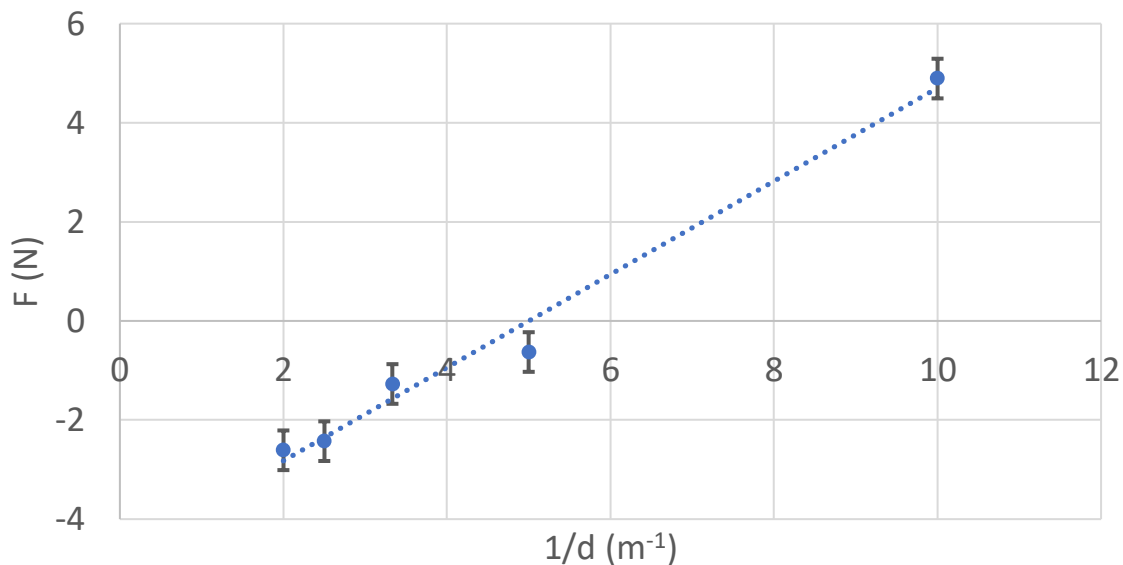
- 9) (5 pts) Three evenly spaced long thin wires carry currents perpendicular to the page, as shown. Wires 1 and 3 carry current I_0 out of the page. Wire 2 carries current of unknown value and direction. Is it possible for the magnetic field at point P to be zero?



- A. It is not possible.
 B. Yes, if wire 2 carries current I_0 into the page.
 C. Yes, if wire 2 carries current I_0 out of the page.
 D. Yes, if wire 2 carries current $2I_0$ into the page.
 E. Yes, if wire 2 carries current $2I_0$ out of the page.

II. Lab multiple choice (15 points)

10) (5 pts) In lab A3 a team placed two minty particles in the VR and observed that the distance between them oscillated, coming close and then moving away repeatedly. They then measured the force on a minty charged particle, F , while varying the distance, d , to another minty particle. Based on their measurements they produced the following graph of F as a function of $1/d$.



Which one of the following statements is consistent with the team’s observation and the graph above?

- A. Positive force is repulsive.
- B. Negative force is repulsive.
- C. The team never measured any repulsive force.
- D. Not enough information is provided.

11) (5 pts) In Lab A4 a team explored a VR simulation that had two different types of exotic particles (not particles with electrical charge). The different types of particles could not be distinguished by their appearance. They spawned two particles and observed that they repelled. What can they conclude?

- A. They must be the same particle type.
- B. They must be different particle types.
- C. They do not have enough information to conclude if they are the same or different particle types.

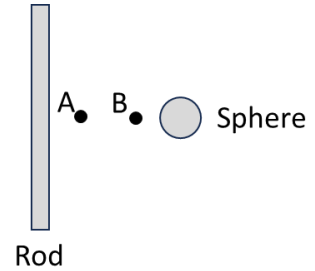
12) (5 pts) Consider the following relationship: $z = xy$. If $x = (10.0 \pm 0.3)$ N, and $y = (20.0 \pm 2.0)$ m, which of the following is consistent with how you should report the value of z according to the rules we use in PHYS 122?

- A. 200 ± 8 N·m
- B. 200 ± 20 N·m
- C. 200.0 ± 20.0 N·m
- D. 200 ± 26 N·m
- E. 200.0 ± 26.0 N·m

III. Lecture free response (25 points)

Use the following scenario for the next three questions.

A charged rod and a charged sphere are fixed in place near each other. The electrical potential is positive on the surface of the rod and negative on the surface of the sphere. The electric potential at infinity is zero. The following questions focus on positions A and B.



- 13) Consider a charged particle (not shown) moving to the right with an initial speed v_0 at point A such that it turns around when it reaches point B. The particle has mass m_p and an absolute value of charge q_p .

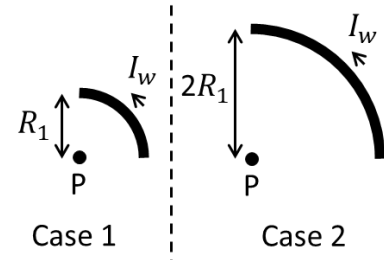
A. (5 pts) Is the particle positively or negatively charged? Explain your reasoning.

B. (7 pts) Write an expression for the electric potential difference between points A and B, $\Delta V_{BA} = V_B - V_A$, in terms of variables given (m_p , v_0 , and q_p). Show your work being sure to mention which equations you are using.

- 14) (6 pts) Consider the initial configuration shown above, if the charged sphere were removed would the electric potential at point A *increase, decrease or remain the same*? Explain your reasoning.

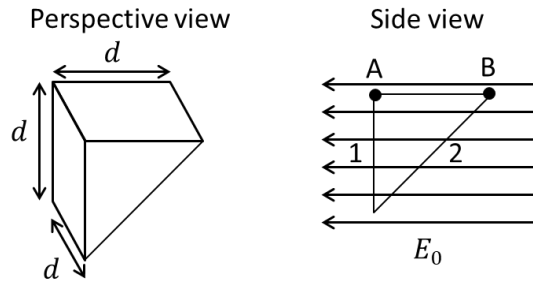
Consider two separate cases with a wire formed into a quarter circle with a current I_w flowing through it, and point P at the center of the circle, as shown. In case 1 the radius of the quarter circle is R_1 and in case 2 the radius is $2R_1$.

- 15) (7 pts) If the magnetic fields at point P in cases 1 and 2, respectively, are B_1 and B_2 , what is the ratio B_2/B_1 ? You should be able to enter a numerical answer but be sure to show your work and to mention which equations you use.



IV. Tutorial free response (15 points)

Consider a triangular prism shaped Gaussian surface with side lengths shown in the perspective view. The Gaussian surface is in a uniform horizontal electric field with magnitude E_0 , as shown in the side view. Surface 1 is the vertical square on the left of the triangular prism, and surface 2 is the sloped rectangle on the right of the triangular prism.



16) (5 pts) Is the absolute value of the flux through surface 1 *greater than*, *less than*, or *equal to* the absolute value of the flux through surface 2? Explain your reasoning.

17) (5 pts) With the original electric field still in place, now a particle with positive charge is placed to the left of surface 1. Does the flux through surface 1 *increase*, *decrease*, or *remain the same*? Explain your reasoning.

18) (5 pts) Now the particle is moved at constant speed a distance $d = 0.50$ m from points A to B. If the particle has charge $q_0 = 3.0 \times 10^{-9}$ C, and $E_0 = 5.0$ N/C, what is the change in potential energy, including the sign, of the particle-field system as the particle is moved from A to B? Show your work being sure to mention which equations you use.

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Constants

Fundamental charge	$e = 1.60 \times 10^{-19} \text{C}$
Electrostatic constant	$K = 8.99 \times 10^9 \text{N}\cdot\text{m}^2\text{C}^{-2}$
Permittivity constant	$\epsilon_0 = \frac{1}{4\pi K} = 8.85 \times 10^{-12} \text{C}^2/(\text{N}\cdot\text{m}^2)$
Permeability constant	$\mu_0 = 1.26 \times 10^{-6} \text{T}\cdot\text{m/A}$
Speed of light	$c = 3.0 \times 10^8 \text{m/s}$

Mathematics

Vector components	$\vec{A} = \vec{A}_x + \vec{A}_y = A_x \hat{i} + A_y \hat{j}$
Vector magnitude	$A = \sqrt{A_x^2 + A_y^2}$
θ ccw from x -axis	$A_x = A \cos \theta$ $A_y = A \sin \theta$ $\theta = \tan^{-1}(A_y/A_x)$
Adding vectors $\vec{C} = \vec{A} + \vec{B}$	$C_x = A_x + B_x$ $C_y = A_y + B_y$
Dot product	$\vec{A} \cdot \vec{B} = AB \cos \alpha$ $\vec{A} \cdot \vec{B} = A_x B_x + A_y B_y$
Cross product	$ \vec{A} \times \vec{B} = AB \sin \alpha$ $\vec{A} \times \vec{B} = -\vec{B} \times \vec{A}$
Area of sphere	$4\pi r^2$
Volume of sphere	$\frac{4}{3}\pi r^3$
Area of cylinder	$2\pi(r^2 + rh)$
Volume of cylinder	$\pi r^2 h$
Sample standard deviation	$s = \sqrt{\frac{\sum_{i=1}^n (x_i - x_{ave})^2}{n-1}}$

Equations from 121

Constant acceleration (in "s" direction)	$v_{fs} = v_{is} + a_s \Delta t$ $s_f = s_i + v_{is} \Delta t + \frac{1}{2} a_s (\Delta t)^2$ $v_{fs}^2 = v_{is}^2 + 2a_s \Delta s$
Newton's 2 nd law	$\vec{a} = \frac{\vec{F}_{net}}{m}$
Newton's 3 rd law	$\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A}$
Kinetic energy	$K = \frac{1}{2} m v^2$

Chapter 22

Coulomb's law	$F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = \frac{K q_1 q_2 }{r^2}$
Force on q due to electric field	$\vec{F}_{on q} = q\vec{E}$
Electric field due to point charge	$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$

Chapter 23

Superposition of electric fields	$\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + \dots$
Magnitude of electric dipole	$p = qs$

Electric field due to an electric dipole:

Along axis of the dipole	$\vec{E}_{dipole} = \frac{1}{4\pi\epsilon_0} \frac{2\vec{p}}{r^3}$
Perpendicular to the dipole	$\vec{E}_{dipole} = -\frac{1}{4\pi\epsilon_0} \frac{\vec{p}}{r^3}$
Linear charge density	$\lambda = \frac{Q}{L}$
Surface charge density	$\eta = \frac{Q}{A}$

Electric field due to:

line of charge	$E_{line} = \frac{1}{4\pi\epsilon_0} \frac{2 \lambda }{r}$
ring of charge	$E_{ring} = \frac{1}{4\pi\epsilon_0} \frac{zQ}{(z^2 + R^2)^{3/2}}$
disc of charge	$E_{disc} = \frac{\eta}{2\epsilon_0} \left[1 - \frac{z}{\sqrt{z^2 + R^2}} \right]$
plane of charge	$E_{plane} = \frac{\eta}{2\epsilon_0}$
sphere of charge where $r > R$	$E_{sphere} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$
between plates of parallel-plate cap.	$E = \frac{Q}{\epsilon_0 A}$

Torque on electric dipole	$\tau = pE \sin \theta$
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Chapter 24

Electric flux through surface:

Flat area and uniform field	$\Phi_e = \vec{E} \cdot \vec{A} = EA \cos \theta$
General	$\Phi_e = \int_{\text{surface}} \vec{E} \cdot d\vec{A}$
Gauss's law	$\Phi_e = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{in}}{\epsilon_0}$

Chapter 25

Potential energy in configuration of

charge between plates of a parallel-plate capacitor $U_{\text{elec}} = qEs$

two point charges $U_{\text{elec}} = \frac{Kq_1q_2}{r}$

dipole in uniform electric field $U_{\text{elec}} = -pE \cos \phi = -\vec{p} \cdot \vec{E}$

Potential energy from potential $U_{\text{elec}} = qV$

Electric potential ($V = 0$ at infinity) due to:

point charge $V_{\text{point}} = \frac{Kq}{r}$

sphere of charge where $r \geq R$ $V_{\text{sphere}} = \frac{KQ}{r}$

ring of charge $V_{\text{ring on axis}} = \frac{KQ}{\sqrt{R^2+z^2}}$

disk $V_{\text{disk on axis}} = \frac{2KQ}{R^2} (\sqrt{z^2 + R^2} - |z|)$

Chapter 26

Potential difference $\Delta V = V_f - V_i = -\int_i^f \vec{E} \cdot d\vec{s}$

Electric field in s direction $E_s = -\frac{dV}{ds}$

Electric field vector $\vec{E} = -\left(\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j} + \frac{\partial V}{\partial z}\hat{k}\right)$

Emf $\mathcal{E} = \frac{W_{\text{chem}}}{q}$

Ideal battery $\Delta V_{\text{bat}} = \mathcal{E}$

Charge on a capacitor $Q = C\Delta V_C$

Capacitance of parallel-plate capacitor $C = \frac{\epsilon_0 A}{d}$

Capacitors in parallel $C_{\text{eq}} = C_1 + C_2 + C_3 + \dots$

Capacitors in series $C_{\text{eq}} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots\right)^{-1}$

Capacitor potential energy $U_C = \frac{Q^2}{2C} = \frac{1}{2}Q\Delta V_C = \frac{1}{2}C(\Delta V_C)^2$

Energy density of electric field $u_E = \frac{1}{2}\epsilon_0 E^2$

Dielectric constant $\kappa = \frac{E_0}{E}$

Capacitance with dielectric $C = \kappa C_0$

Induced charge density $\eta_{\text{induced}} = \eta_0 \left(1 - \frac{1}{\kappa}\right)$

Chapter 27

Electron current in wire $i_e = n_e A v_d$

Current $I = \frac{dQ}{dt}$

Current density $J = \frac{I}{A}$

Kirchoff's junction law $\sum I_{\text{in}} = \sum I_{\text{out}}$

Current density $J = \sigma E$

Conductivity $\sigma = \frac{n_e e^2 \tau}{m}$

Resistivity $\rho = \frac{1}{\sigma}$

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

Ohm's law $I = \frac{\Delta V}{R}$

Chapter 29

Superposition of magnetic fields $\vec{B}_{\text{net}} = \vec{B}_1 + \vec{B}_2 + \dots$

Magnetic field of

point charge $\vec{B}_{\text{point charge}} = \frac{\mu_0 q \vec{v} \times \hat{r}}{4\pi r^2}$

current segment $\vec{B}_{\text{current segment}} = \frac{\mu_0 I \Delta \vec{s} \times \hat{r}}{4\pi r^2}$

long straight wire $B_{\text{wire}} = \frac{\mu_0 I}{2\pi r}$

N-turn current loop $B_{\text{coil center}} = \frac{\mu_0 NI}{2R}$

Magnetic dipole magnitude $m = AI$

Magnetic field due to dipole on axis $\vec{B}_{\text{dipole}} = \frac{\mu_0 2\vec{m}}{4\pi z^3}$

Ampère's law $\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}}$

Magnetic field due to solenoid $B = \mu_0 nI$

Force on moving charge in B field $F_{\text{on q}} = |q|vB \sin \alpha$

Force on moving charge in B field $\vec{F}_{\text{on q}} = q\vec{v} \times \vec{B}$

Force on wire in B field $F_{\text{wire}} = IlB \sin \alpha$

Force on wire in B field $\vec{F}_{\text{wire}} = I\vec{l} \times \vec{B}$

Radius of cyclotron orbit $r_{\text{cyc}} = \frac{mv}{|q|B}$

Torque on magnetic dipole in B field $\vec{\tau} = \vec{m} \times \vec{B}$