Physics 51"Study Guide" for Midterm 2 ("Laundry List" of important concepts)Todd SaukeConcept(important concepts in bold; vectors also shown in bold)Symbol or EquationPrerequisites:

Physics quantities are typ. either scalars or vectors (magnitude & direction)	components of vectors add
From mechanics , total external force on a body = mass x acceleration	$\Sigma \mathbf{F}_{ext} = \mathbf{m} \mathbf{a}$ (SI newton, "N")
Mass (SI kilogram, "kg") resists change in motion (via "momentum", p)	$\mathbf{p} = \mathbf{m}\mathbf{v}, \mathbf{F}_{ext} = d\mathbf{p}/dt$
A mass moving in a circle undergoes centripetal acceleration	$a_{centr} = v^2 / r$
Conservation of linear momentum : Isolated system ($\Sigma \mathbf{F}_{ext} = 0$) $\Rightarrow \Delta \mathbf{p}=0$; $\mathbf{p}_f=\mathbf{p}_i$	$m_1 v_{f1} + m_2 v_{f2} = m_1 v_{i1} + m_2 v_{i2}$
A moving mass has energy of motion, "Kinetic Energy" (SI joule, "J")	$KE = \frac{1}{2} m v^2$ (a scalar)
A spring being compressed pushes back proportional to compression	$\mathbf{F} = -\mathbf{k} \mathbf{x}$
A compressed spring has energy of compression, elastic "Potential Energy'	$U = \frac{1}{2} k x^{2}$
For conservative forces, mechanical energy is conserved	$E = KE + PE = constant (W_{nc} = 0)$

Electromagnetics:

Electric Charge is the fundamental quantity in Electrostatics Charge is conserved, quantized, and comes in "positive" and "negative" Like charges repel (**radially**); opposite charges attract; **Coulomb's Law** The constant ε_0 is numerically related (by definition) to the speed of light, c All "normal" matter is made up of **protons, neutrons** and **electrons** Define the proton of the speed of light, c $\varepsilon_0 = 10^7 / (4\pi c^2) = 8.854 \times 10^{-12}$ Coulomb's $k=1/(4\pi \varepsilon_0)=8.99 \times 10^{-27} k^{-10}$

Protons have +e charge; electrons have -e. Their mutual attraction holds everything together. In a conductor, electrons are free to move around.
Total force (vector) is the vector sum of individual forces (superposition)
The Electric field vector is the force per unit charge on a "test charge", q₀

For distributions of charge (eg. λ , σ), vector integrate over the distribution **Field lines** provide a graphical **representation** of **E** (and **B**) fields An **Electric Dipole** is a separation of equal magnitude, opposite charges An Electric Dipole, **p**, in an Electric field, **E**, experiences a torque An Electric Dipole oriented in an Electric field has potential energy, U

Electric Flux; "flow" of **E** through a surface. (dA is a vector \perp to surface)

Gauss's Law expresses the fact that the source of (static) flux is charge Charge on a conductor at rest resides on its *surface*. Also for conductor \rightarrow Use Gauss's Law to determine E field for **symmetric** charge distributions Gauss's Law easily shows E from a line of charge (instead of nasty integral) A symmetric distribution will be easier to solve for E using Gauss's Law Electric force from a **static** charge distribution is a **conservative** force Work done on "test charge" is path-independent change in **potential energy** U=qV **Electric Potential** is potential energy per unit charge (SI volt, "V") V=U/q

We always speak of "**potential difference**" (the zero is chosen for convenience) The reverse of this is that **E** field is the (minus) gradient of the potential **Equipotential surfaces** are everywhere perpendicular to the E field lines A **capacitor** (any pair of separated conductors) holds charge per volt Capacitance depends ONLY on geometry (& what's between conductors) When capacitors are connected in **parallel**, the **equivalent capacitance** is: When in **series**, capacitors have an **equivalent capacitance** given by: It takes work (energy) to charge a capacitor. W = potential energy, U **Energy** (U) stored in a capacitor "**resides**" *in* **the electric field** If the insulation separating capacitor conductors is dielectric, not vacuum:

O (SI coulomb, "C") $e = 1.602 \times 10^{-19} C$ $F = 1/(4 \pi \epsilon_0) q_1 q_2 / r^2$ Coulomb's $k=1/(4\pi \epsilon_0)=8.99 \times 10^9$ $m_p = 1.67 \times 10^{-27} \text{ kg}$ $m_e = 9.11 \times 10^{-31} \text{ kg}$ $\mathbf{F} = \Sigma \mathbf{F}_{i}$ $\mathbf{E} = \mathbf{F}_0 / \mathbf{q}_0$ $\mathbf{F} = \mathbf{q} \mathbf{E}$ $\mathbf{E} = \int d\mathbf{E} = \int dq / (4 \pi \varepsilon_0 r^2) \, \mathbf{\hat{r}}$ E strong where lines are dense $\mathbf{p} = q\mathbf{d} (\mathbf{d} = separation - \mathbf{i})$ $\tau = p \times E$ $\tau = p E \sin(\phi)$ $\mathbf{U} = -\mathbf{p} \cdot \mathbf{E} = -\mathbf{p} \mathbf{E} \cos(\phi)$ $\Phi_{\rm E} = \int \mathbf{E} \cdot d\mathbf{A}$ (through surface) $\Phi_{\rm E} = \int \mathbf{E} \cdot d\mathbf{A} = Q_{\rm encl} / \varepsilon_0$ $\mathbf{E}_{\text{inside}} = 0$ (for static case) eg. $E = \sigma / 2\epsilon_0$ (for sheet) $\mathbf{E} = \lambda / (2 \pi \varepsilon_0 \mathbf{r})$ eg.E= σ/ϵ_0 (between two cond. plates)

 $V = qV \qquad U = q_0/(4\pi\epsilon_0)\Sigma q_i/r_i$ $V = U/q \qquad V = 1/(4\pi\epsilon_0)\Sigma q_i/r_i$ $V_a - V_b = \int \mathbf{E} \cdot d\mathbf{l}$ $\mathbf{E} = -\mathbf{Grad} (V)$

C = Q / V_{ab} (SI farad, "F") C = ε_0 A / d (parallel plates) C_{eq} = C₁ + C₂ + C₃ + ... ¹/C_{eq}=¹/C₁ + ¹/C₂ + ¹/C₃+... U= ¹/₂Q²/C = ¹/₂CV² = ¹/₂QV u = ¹/₂ ε_0 E² (u = U-density) just replace ε_0 with ε = k ε_0 ! **Current** is the amount of charge flowing through an area per unit time In a conductor (non-static case now!), free charges (typ. electrons) can move (with drift velocity, v_d) in response to an Electric field

The current per unit area is called **current density** (a vector!) Even conductors have resistance to the flow of charge (material dependent) The resistivity of a material is temperature dependent, typ. increasing w/ T A source of **electromotive force** (emf or \mathcal{E}) makes current flow in a circuit For materials obeying **Ohm's Law**, current is proportional to voltage The ratio V/I is called **resistance** and is related to a material's resistivity Current flowing through a resistor is accompanied by a **voltage drop** An "ideal" source of emf supplies a perfectly constant voltage to the circuit A real source of emf (eg. a battery) has **internal resistance**, r (voltage drop) A circuit element with potential difference, V_{ab}, across it and current, I,

flowing through it is a source or sink of **power** depending on sign of I When resistors are connected in **series**, the **equivalent resistance** is: When in **parallel**, resistors have an **equivalent resistance** given by: Series resistors all have the same current; when in parallel, the same voltage **Kirchhoff's junction rule** (based on conservation of charge) **Kirchhoff's loop rule** (based on conservation of energy) Use Kirchoff's rules to generate equations ("n equations in n unknowns") An "ideal" ammeter has zero resistance and measures the current through it An "ideal" voltmeter has ∞r_{in} & measures voltage across probed points When a circuit ("**RC circuit**") has a capacitor being charged or discharged by a series resistor, the current and charge are not constant. Kirchhoff's loop-rule equation for the circuit results in a differential equation, the solution of which involves decaying exponentials:

The product of R & C has units of time and is called the "time constant" τ Magnetic interactions are interactions between moving charged particles Magnetic interactions are described by the vector field, **B** (SI tesla, "T") The magnetic force is **always perpendicular** to **v** (and **B**): no work done Just like for **E**, field lines provide a graphical representation of **B** fields

Magnetic Flux; "flow" of B through a surface (again, just like with E)

Gauss's law for magnetism: there are **no "magnetic monopoles"** In a uniform **B** field: charged particle goes in circle (or spiral) of radius, R Crossed **E** and **B** fields: velocity selector (when $F_{net}(v) = 0$, no deflection) For a current carrying wire in a magnetic field, there is a force on the wire A current loop of area A & current I in a uniform magnetic field **B** has $F_{net} = 0$ But it does experience a torque, τ , in terms of magnetic moment, μ . The work done by the torque can be described as a potential energy A moving charge q with velocity **v** creates a magnetic field **B** that depends

on distance as $1/r^2$, & is perpendicular to both v and $\hat{\mathbf{r}}$ the unit vector from the "source point" (at q) to the "field point" (at B).

The constant μ_0 is defined so that, together with ϵ_0 , they relate to c The total **B** from several moving charges is the vector sum of the fields

produced by the individual charges (superposition)

The **Biot-Savart law** gives the previous relations in terms of current in wire $\mathbf{B} = \int d\mathbf{B} = \int (\mu_0/4\pi) \mathbf{I} \, d\mathbf{I} \times \hat{\mathbf{r}} / r^2$

I = dQ/dt (SI ampere, "A") $I = n q v_d A \qquad (A = area)$ (above: n = charge density) $J = n q v_d$ $\rho = E / J (\rho = "resistivity")$ $\rho(T) = \rho_0 [1 + \alpha (T - T_0)]$ & is provider of voltage, V V = I R $R = \rho L / A \text{ (SI ohm, "}\Omega")$ label R w/'+' & '-' in diagrams!

$$V_{ab} = \mathcal{E} - I r$$

$$P = V_{ab}I = I^2 R = V^2/R \text{ (SI watt, "W")}$$
(a resistor **always** takes energy out)
$$R_{eq} = R_1 + R_2 + R_3 + \dots$$

$$^1/R_{eq} = ^1/R_1 + ^1/R_2 + ^1/R_3 + \dots$$

$$\begin{array}{l} \Sigma \ \ I \ = 0 \\ \Sigma \ \ V \ = 0 \end{array}$$

$$\begin{split} \Delta V_{ammeter} &= 0\\ I_{in_voltmeter} &= 0 \text{ (admits no current)}\\ q &= C \mathcal{E}(1 - e^{-t/(RC)}) = Q_f(1 - e^{-t/(RC)})\\ i &= I_0 e^{-t/(RC)} \text{ (for charging)}\\ q &= Q_0 e^{-t/(RC)}\\ i &= I_0 e^{-t/(RC)} \text{ (for discharging)}\\ \tau &= RC \text{ , (in } e^{-t/\tau}) \end{split}$$

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$$
 (right-hand-rule)

B field lines form **closed** loops $\Phi_{mag} = \int \mathbf{B} \cdot d\mathbf{A}$ $\Phi_{mag} = \int \mathbf{B} \cdot d\mathbf{A} = 0 \text{ (closed surface)}$ $R = mv / (qB) ; \omega = qB / m$ $v_{selected} = E / B$ $\mathbf{F} = \int d\mathbf{F} = \int I \, d\mathbf{I} \times \mathbf{B}$ $\boldsymbol{\mu} = n \ I \ \mathbf{A} \text{ (for n loops)}$ $\boldsymbol{\tau} = \boldsymbol{\mu} \times \mathbf{B} \quad \boldsymbol{\tau} = \boldsymbol{\mu} B \sin(\phi)$ $U = -\boldsymbol{\mu} \cdot \mathbf{B} = -\boldsymbol{\mu} B \cos(\phi)$

$$\mathbf{B} = (\mu_0 / 4\pi) \ \mathbf{qv} \ \mathbf{x} \ \mathbf{\hat{r}} / r^2$$

$$\mu_0 = 4 \ \pi \ \mathbf{x} \ 10^{-7}$$

$$\mathbf{c}^2 = \frac{1}{2} / (\varepsilon_0 \ \mu_0)$$

 $\mathbf{B} = \int d\mathbf{B} = \int (\mu_0/4\pi) \, \mathrm{d}\mathbf{q}\mathbf{v} \, \mathbf{x} \, \mathbf{\hat{r}} / r^2$ $\mathbf{B} = \int d\mathbf{B} = \int (\mu_0/4\pi) \, \mathrm{I} \, \mathrm{d}\mathbf{l} \, \mathbf{x} \, \mathbf{\hat{r}} / r^2$

From this law, the **B** field from a long, straight current carrying wire is: and the **right-hand-rule** gives the direction that **B** curls around the wire

The force per length between two long, parallel current carrying wires is attractive if currents are in the same direction, repulsive if opposite

B at distance x along axis of conducting loop (N turns, radius a, current I)

Ampere's Law relates the line integral of **B** around any closed path to the net current through any area bounded (encircled) by the path

We apply Ampere's law to a highly symmetric situation where we can choose the integration loop (through field point P) to have constant B aligned with the path (or \perp)

The **B** field inside of a long solenoid with n turns per unit length is:

B inside a toroidal solenoid (N turns) at distance r from symmetry axis: B field outside the space enclosed by a tightly wound solenoid is near 0 B field **inside** a long cylindrical conductor of radius R is easy using Ampere's Law When magnetic materials are present, there is an effect on the B field

B=
$$\mu_0 I / (2\pi r)$$
 (at distance r)

$$F / L = \mu_0 I I' / (2\pi r)$$

 $\mathbf{B}_{x} = \mu_{0} \text{ N I } a^{2} / 2 (x^{2} + a^{2})^{3/2}$

 $JB \cdot dl = \mu_0 I_{enc} \text{ (closed loop)}$ $I_{enc} \text{ includes displacement current}$ Choose integration *path* through P to make the integral easy $B = \mu_0 n I \text{ (near the center)}$ $B = \mu_0 N I / (2 \pi r)$ $B \approx 0 \text{ (outside solenoid)}$ $B = \mu_0 Ir / (2\pi R^2) \text{ inside cylinder}$ just replace $\mu_0 \text{ with } \mu = K_m \mu_0!$