Physics 51 "Study Guide" for Midterm 2 ("Laundry List" of important concepts) Todd Sauke Concept (important concepts in bold; vectors also shown in bold) Symbol or Equation Prerequisites:
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 $\quad \Sigma \mathbf{F}_{\text {ext }}=\mathrm{m} \mathbf{a}$ (SI newton, "N")
Mass (SI kilogram, "kg") resists change in motion (via "momentum", p)
A mass moving in a circle undergoes centripetal acceleration
Conservation of linear momentum: Isolated system $\left(\Sigma \mathbf{F}_{\text {ext }}=0\right) \rightarrow \Delta \mathbf{p}=0 ; \mathbf{p}_{\mathrm{f}}=\mathbf{p}_{\mathrm{i}}$
A moving mass has energy of motion, "Kinetic Energy" (SI joule, "J")
A spring being compressed pushes back proportional to compression
A compressed spring has energy of compression, elastic "Potential Energy" $\mathrm{U}=1 / 2 \mathrm{k} \mathrm{x}^{2}$
For conservative forces, mechanical energy is conserved
$\mathrm{E}=\mathrm{KE}+\mathrm{PE}=$ constant $\left(\mathrm{W}_{\mathrm{nc}}=0\right)$

## 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 $\varepsilon_{0}$ is numerically related (by definition) to the speed of light, c All "normal" matter is made up of protons, neutrons and electrons
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", $\mathrm{q}_{0}$
For distributions of charge (eg. $\lambda, \sigma$ ), vector integrate over the distribution
Field lines provide a graphical representation of $\mathbf{E}$ (and $\mathbf{B}$ ) fields
An Electric Dipole is a separation of equal magnitude, opposite charges
An Electric Dipole, $\mathbf{p}$, in an Electric field, $\mathbf{E}$, experiences a torque
Q (SI coulomb, "C")
$\mathrm{e}=1.602 \times 10^{-19} \mathrm{C}$
$\mathrm{F}=1 /\left(4 \pi \varepsilon_{0}\right) \mathrm{q}_{1} \mathrm{q}_{2} / \mathrm{r}^{2}$
$\varepsilon_{0}=10^{7} /\left(4 \pi \mathrm{c}^{2}\right)=8.854 \times 10^{-12}$
Coulomb's k $=1 /\left(4 \pi \varepsilon_{0}\right)=8.99 \times 10^{9}$
$\mathrm{m}_{\mathrm{p}}=1.67 \times 10^{-27} \mathrm{~kg}$
$\mathrm{m}_{\mathrm{e}}=9.11 \times 10^{-31} \mathrm{~kg}$
$\mathbf{F}=\Sigma \mathbf{F}_{\mathrm{i}}$
$\mathbf{E}=\mathbf{F}_{0} / \mathrm{q}_{0} \quad \mathbf{F}=\mathrm{q} \mathbf{E}$
$\mathbf{E}=\int_{\mathrm{d} \mathbf{E}}=\int_{\mathrm{dq}} /\left(4 \pi \varepsilon_{0} \mathrm{r}^{2}\right) \hat{\mathbf{r}}$
$E$ strong where lines are dense
$\mathbf{p}=\mathrm{qd}(\mathbf{d}=$ separation $-\rightarrow+)$
An Electric Dipole oriented in an Electric field has potential energy, U
$\tau=\mathbf{p} \times \mathbf{E} \quad \tau=\mathrm{p} \mathrm{E} \sin (\phi)$
$\mathrm{U}=-\mathbf{p} \cdot \mathbf{E}=-\mathrm{p} \mathrm{E} \cos (\phi)$
Electric Flux; "flow" of $\mathbf{E}$ 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 $\mathbf{E}$ 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
$\Phi_{\mathrm{E}}=\int \mathbf{E} \cdot \mathrm{d} \mathbf{A}$ (through surface)
$\Phi_{\mathrm{E}}=\int \mathbf{E} \cdot \mathrm{d} \mathbf{A}=\mathrm{Q}_{\mathrm{encl}} / \varepsilon_{0}$
$\mathbf{E}_{\text {inside }}=0 \quad$ (for static case)
eg. $\mathrm{E}=\sigma / 2 \varepsilon_{0} \quad$ (for sheet)
$\mathrm{E}=\lambda /\left(2 \pi \varepsilon_{0} \mathrm{r}\right)$
eg. $\mathrm{E}=\sigma / \varepsilon_{0}$ (between two cond. plates) Electric force from a static charge distribution is a conservative force
Work done on "test charge" is path-independent change in potential energy $U=q V \quad U=q_{0} /\left(4 \pi \varepsilon_{0}\right) \sum q_{i} / r_{i}$
Electric Potential is potential energy per unit charge (SI volt, "V")
We always speak of "potential difference" (the zero is chosen for convenience)
The reverse of this is that $\mathbf{E}$ 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:
$\mathrm{V}=\mathrm{U} / \mathrm{q} \quad \mathrm{V}=1 /\left(4 \pi \varepsilon_{0}\right) \sum \mathrm{q}_{\mathrm{i}} / \mathrm{r}_{\mathrm{i}}$
$\mathrm{V}_{\mathrm{a}}-\mathrm{V}_{\mathrm{b}}=\int \mathbf{E} \cdot \mathrm{d} \mathbf{l}$
$\mathbf{E}=-\boldsymbol{G r a d}(\mathrm{V})$
$\mathrm{C}=\mathrm{Q} / \mathrm{V}_{\mathrm{ab}}$ (SI farad, "F")
$\mathrm{C}=\varepsilon_{0} \mathrm{~A} / \mathrm{d}$ (parallel plates)
$\mathrm{C}_{\mathrm{eq}}=\mathrm{C}_{1}+\mathrm{C}_{2}+\mathrm{C}_{3}+\ldots$
${ }^{1} / \mathrm{C}_{\mathrm{eq}}={ }^{1} / \mathrm{C}_{1}+{ }^{1} / \mathrm{C}_{2}+{ }^{1} / \mathrm{C}_{3}+\ldots$
$\mathrm{U}=1 / 2 \mathrm{Q}^{2} / \mathrm{C}=1 / 2 \mathrm{CV}^{2}=1 / 2 \mathrm{QV}$
$u=1 / 2 \varepsilon_{0} E^{2}$ ( $u=$ U-density)
just replace $\varepsilon_{0}$ with $\varepsilon=\mathrm{k} \varepsilon_{0}$ !

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, $\mathrm{v}_{\mathrm{d}}$ ) 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 $\mathfrak{E}$ ) 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, $\mathrm{V}_{\mathrm{ab}}$, 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 $\infty \mathrm{r}_{\text {in }} \&$ 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" $\tau$ 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 $\mathbf{v}$ (and $\mathbf{B}$ ): no work done Just like for $\mathbf{E}$, field lines provide a graphical representation of $\mathbf{B}$ 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 $\mathbf{B}$ field: charged particle goes in circle (or spiral) of radius, R Crossed $\mathbf{E}$ and $\mathbf{B}$ fields: velocity selector (when $\mathrm{F}_{\text {net }}(\mathrm{v})=0$, 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 $\mathbf{B}$ has $\mathbf{F}_{\text {net }}=0$
But it does experience a torque, $\tau$, in terms of magnetic moment, $\mu$.
The work done by the torque can be described as a potential energy
A moving charge $q$ with velocity $\mathbf{v}$ creates a magnetic field $\mathbf{B}$ that depends on distance as $1 / r^{2}, \&$ is perpendicular to both $\mathbf{V}$ and $\hat{\mathbf{r}}$ the unit vector from the "source point" (at q) to the "field point" (at B).
The constant $\mu_{0}$ is defined so that, together with $\varepsilon_{0}$, they relate to $\mathbf{c}$ The total $\mathbf{B}$ 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
$\mathrm{I}=\mathrm{dQ} / \mathrm{dt}$ (SI ampere, "A")
$\mathrm{I}=\mathrm{nq} \mathrm{v}_{\mathrm{d}} \mathrm{A} \quad(\mathrm{A}=$ area)
(above: $\mathrm{n}=$ charge density)
$\mathbf{J}=\mathrm{nq} \mathbf{V}_{\mathrm{d}}$
$\rho=\mathrm{E} / \mathrm{J}(\rho=$ "resistivity")
$\rho(T)=\rho_{0}\left[1+\alpha\left(T-T_{0}\right)\right]$
$\mathcal{E}$ is provider of voltage, V
$\mathrm{V}=\mathrm{I} \mathrm{R}$
$\mathrm{R}=\rho \mathrm{L} / \mathrm{A}$ (SI ohm, " $\Omega$ ")
label R w/ '+' \& '-' in diagrams!
$V_{a b}=\mathcal{E}-I r$
$\mathrm{P}=\mathrm{V}_{\mathrm{ab}} \mathrm{I}=\mathrm{I}^{2} \mathrm{R}=\mathrm{V}^{2} / \mathrm{R}$ (SI watt, "W")
(a resistor always takes energy out)
$\mathrm{R}_{\mathrm{eq}}=\mathrm{R}_{1}+\mathrm{R}_{2}+\mathrm{R}_{3}+\ldots$
${ }^{1} / \mathrm{R}_{\mathrm{eq}}={ }^{1} / \mathrm{R}_{1}+{ }^{1} / \mathrm{R}_{2}+{ }^{1} / \mathrm{R}_{3}+\ldots$
$\Sigma \mathrm{I}=0$
$\Sigma \mathrm{V}=0$
$\Delta \mathrm{V}_{\text {ammeter }}=0$
$\mathrm{I}_{\mathrm{in} \text { _voltmeter }}=0$ (admits no current)
$\mathrm{q}=\mathrm{C} \delta\left(1-\mathrm{e}^{-t /(R C)}\right)=\mathrm{Q}_{\mathrm{f}}\left(1-\mathrm{e}^{-\mathrm{t} /(\mathrm{RC})}\right)$
$\mathrm{i}=\mathrm{I}_{0} \mathrm{e}^{-\mathrm{t} /(\mathrm{RC})}$ (for charging)
$\mathrm{q}=\mathrm{Q}_{0} \mathrm{e}^{-\mathrm{t} /(\mathrm{RC})}$
$\mathrm{i}=\mathrm{I}_{0} \mathrm{e}^{-\mathrm{t} /(\mathrm{RC})}$ (for discharging)
$\tau=R C$, (in $\left.\mathrm{e}^{-t / \tau}\right)$
$\mathbf{F}=\mathrm{qv} \mathbf{x B}$ (right-hand-rule)
B field lines form closed loops
$\Phi_{\mathrm{mag}}=\int \mathbf{B} \cdot \mathrm{d} \mathbf{A}$
$\Phi_{\text {mag }}=\int \mathbf{B} \cdot \mathrm{d} \mathbf{A}=0$ (closed surface)
$\mathrm{R}=\mathrm{mv} /(\mathrm{qB}) ; \omega=\mathrm{qB} / \mathrm{m}$
$\mathrm{v}_{\text {selected }}=\mathrm{E} / \mathrm{B}$
$\mathbf{F}=\int_{\mathrm{d}} \mathbf{F}=\int \mathrm{I} \mathrm{d} \mathbf{l} \mathbf{x} \mathbf{B}$
$\boldsymbol{\mu}=\mathrm{n}$ I A (for n loops)
$\tau=\mu \mathbf{x} \mathbf{B} \quad \tau=\mu \mathrm{B} \sin (\phi)$
$\mathrm{U}=-\mu \cdot \mathbf{B}=-\mu \mathrm{B} \cos (\phi)$
$\mathbf{B}=\left(\mu_{0} / 4 \pi\right) \mathrm{q} \mathbf{V} \mathbf{x} \hat{\mathbf{r}} / \mathrm{r}^{2}$
$\mu_{0}=4 \pi \times 10^{-7}$
$c^{2}={ }^{1} /\left(\varepsilon_{0} \mu_{0}\right)$
$\mathbf{B}=\int \mathrm{d} \mathbf{B}=\int\left(\mu_{0} / 4 \pi\right) \mathrm{dq} \mathbf{v} \mathbf{x} \hat{\mathbf{r}} / \mathrm{r}^{2}$
$\mathbf{B}=\int \mathrm{d} \mathbf{B}=\int\left(\mu_{0} / 4 \pi\right) \mathrm{I} \mathrm{d} \mathbf{x} \hat{\mathbf{r}} / \mathrm{r}^{2}$

From this law, the $\mathbf{B}$ field from a long, straight current carrying wire is: and the right-hand-rule gives the direction that $\mathbf{B}$ 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 $\mathbf{B}$ 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 $\mathbf{B}$ 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
$\mathrm{B}=\mu_{0} \mathrm{I} /(2 \pi \mathrm{r})$ (at distance r$)$
$\mathrm{F} / \mathrm{L}=\mu_{0} \mathrm{II} \mathrm{I}^{\prime} /(2 \pi \mathrm{r})$
$\mathbf{B}_{\mathrm{x}}=\mu_{0} \mathrm{NI} \mathrm{a}^{2} / 2\left(\mathrm{x}^{2}+\mathrm{a}^{2}\right)^{3 / 2}$
$\int \mathbf{B} \cdot \mathbf{d} \mathbf{l}=\mu_{0} I_{\text {enc }}$ (closed loop)
$\mathrm{I}_{\text {enc }}$ includes displacement current Choose integration path through P to make the integral easy
$B=\mu_{0} n I$ (near the center)
$B=\mu_{0} N I /(2 \pi r)$
$\mathrm{B} \approx 0$ (outside solenoid)
$B=\mu_{0} \operatorname{Ir} /\left(2 \pi R^{2}\right)$ inside cylinder just replace $\mu_{0}$ with $\mu=K_{m} \mu_{0}$ !

