PHYSICS 200

Foundations of Physics II

Electricity and Magnetism

PHYS 200
Sections 01A & 02A
MTRF 1:30 & 1:00
PEngel 167 & 173

Text:
University Physics
Young & Freedman

Spring 2021
Blocks C & D
Tom Kirkman

As in PHYS 191, homework will be assigned via `Pearson’s Mastering Physics`. Note that these homework problems are selected from the chapter-end problems in our textbook. Generally homework is due before midnight on the following lecture day. Since I’ve not used Mastering Physics before my knowledge about its workings is quite limited. If/when you have problems use direct email to contact me: I’ve seen too many in-application messaging systems fail, leaving your questions floating in the ether. While the web promises global connections, it often promotes isolation. Consider forming a problem solving group. Or just work the homework with classmates in our “Physics Library” PEngel 102; I'll then be near by when you have questions. Note that assigned homework should just be the start to developing your problem solving skills: work extra odd problems and check the answer in the back of the textbook! You might also check out some data-based results of using online problem systems like Mastering:

http://www.physics.csbsju.edu/lab/McKay:copy&fail.mp4

Based on data Professor McKay says:
“in order to learn things in physics your homework must be done earnestly”

Register online from the Mastering sign-in page:
www.pearson.com/mastering/physics

I imagine your username/password from 191 will still be valid.

Enter the course ID immediately following registration

Block C: enroll starting Mar 15 **Course ID:** kirkman94651
Block D: enroll starting Apr 14 **Course ID:** kirkman21706

Topic 1 – Electric Charges and Fields
Class 1

Reading: Chapter 21

Objectives:

1. Be able to describe the difference between **conductors** and **insulators**.
2. Be able to describe the conservation and quantization of electric charge.
3. Be able to describe how to charge by friction, conduction, and induction.
4. Be able to describe polarization.
5. Be able to calculate electric forces using **Coulomb's Law**.
6. Be able to calculate **electric fields** due to point charges and charge densities (λ, σ, ρ)
7. Be able to use superposition (vector addition) to find the electric field when multiple sources are present
8. Be able to draw and interpret electric field lines.
9. Recognize and explain quantitatively electric dipoles $\vec{\boldsymbol{p}} = q\vec{\boldsymbol{d}}$

Equations to Know from Memory:

Coulomb's Law: $F = \frac{1}{4\pi\epsilon_0}\frac{|q_1|\,|q_2|}{r^2}$ Electric Field: $\vec{\boldsymbol{E}} \equiv \frac{\vec{\boldsymbol{F}}}{q_0} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}\hat{\boldsymbol{r}}$

Electric Field along axis of ring: $E_x = k_e Q \frac{x}{(x^2+R^2)^{3/2}}$

dipoles: $\vec{\boldsymbol{\tau}} = \vec{\boldsymbol{p}} \times \vec{\boldsymbol{E}}$ $U = -\vec{\boldsymbol{p}} \cdot \vec{\boldsymbol{E}}$

Physical Constants to Understand:

Fundamental Charge: $e = 1.6 \times 10^{-19}\ \mathrm{C}$
Permittivity of Free Space: $\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2}$
Coulomb Constant: $k_e = \frac{1}{4\pi\epsilon_0} = 8.9875 \times 10^9\ \mathrm{N \cdot m^2/C^2} \approx 9 \times 10^9\ \mathrm{N \cdot m^2/C^2}$

Topic 2 – Gauss's Law
Class 2

Reading: Chapter 22

Objectives:

1. Be able to calculate electric flux and apply **Gauss's Law** to situations with high symmetry
2. Be able to describe surface integrals
3. Be able to describe how charge is distributed on conductors and why the electric field is zero inside conductors

Equations to Know from Memory:

Electric Flux: $\Phi_E = EA\cos\theta$ $\Phi_E \equiv \int \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{A}}$

Gauss's Law: $\Phi_E = \dfrac{Q_{\text{inside}}}{\epsilon_0}$ for a closed surface

outside of a conductor: $E = \dfrac{\sigma}{\epsilon_0}$ charged sheet: $E = \dfrac{\sigma}{2\epsilon_0}$

charged infinite wire: $E = \dfrac{\lambda}{2\pi\epsilon_0 r}$ inside uniform sphere: $E_r = k_e Q \dfrac{r}{R^3} = \dfrac{\rho r}{3\epsilon_0}$

surface area of sphere: $4\pi R^2$ volume of sphere: $\dfrac{4}{3}\pi R^3$

surface area of cylinder $2\pi Rl$ volume of cylinder: $\pi R^2 l$

Topic 3 – Electrical Potential
Class 3

Reading: Chapter 23

Objectives:

1. Be able to describe **electric potential** (in volts) and **electrical potential energy** (in J).
2. Know that the zero for electric potential (called **ground**), like zero for potential energy, is a choice. Often the electric potential is chosen to be zero at infinity.
3. Be able to calculate electric potential differences. Note the textbook will sometimes abbreviate: $\Delta V \rightarrow V$ nevertheless voltages are always voltage **differences,** e.g., the voltage difference between capacitor plates
4. Be able to use **superposition** to calculate electric potential and electrical potential energy if multiple sources are present.
5. Be able to use electrical potential energy to describe the motion of particles when total energy is conserved.

Equations to Know from Memory:

Change in potential energy: $W_{ab} = -\Delta U = -q\Delta V = \Delta KE$

Potential Difference: $\Delta V = \dfrac{\Delta U}{q}$ in uniform E-field: $\Delta V = -\vec{\boldsymbol{E}} \cdot \Delta \vec{\boldsymbol{r}}$

Electric Potential: point: $V = \dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{r}$ line: $V = \dfrac{-\lambda}{2\pi\epsilon_0}\ln(r)$

$$V_b - V_a = -\int_a^b \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{l}} = -\int_a^b E\,\cos\theta\, dl$$

$$E_x = -\frac{\partial V}{\partial x} \qquad E_y = -\frac{\partial V}{\partial y} \qquad E_z = -\frac{\partial V}{\partial z}$$

Potential Energy: $PE = \dfrac{1}{4\pi\epsilon_0}\dfrac{q_1 q_2}{r}$

Physical Constants and Units to Understand:

Volt: $1\text{ V} = 1\text{ J/C}$
Electron Volt: $1\text{ eV} = 1.6 \times 10^{-19}\text{ J}$
Electric Field: $1\text{ N/C} = 1\text{ V/m}$

Topic 4 – Capacitance and Dielectrics
Class 4

Reading: Chapter 24

Objectives:

1. Be able to describe the operation of a **capacitor** and calculate capacitance based on electrical measurements and physical attributes.
2. Be able to calculate the equivalent capacitance for **series, parallel**, and complex combinations of capacitors.
3. Be able to calculate the **energy stored** in a capacitor.
4. Be able to describe how **dielectrics** modify electric fields. Be able to define **dielectric constant** K and **permittivity** ϵ
5. Be able to describe how dielectrics work at the atomic level
6. Be able to apply **Gauss's Law** in dielectrics

Equations to Know from Memory:

Capacitance: $C \equiv \frac{Q}{\Delta V}$ Parallel-Plate Capacitor: $C = K\epsilon_0 \frac{A}{d} = \epsilon \frac{A}{d}$

Energy Stored in Capacitor: $U = \frac{1}{2}Q(\Delta V) = \frac{1}{2}C(\Delta V)^2 = \frac{Q^2}{2C}$ $u = \frac{1}{2}\epsilon_0 E^2$

Capacitors in Parallel: $C_{\mathrm{eq}} = C_1 + C_2 + C_3 + \cdots$

Capacitors in Series: $\frac{1}{C_{\mathrm{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$

$$\int K\vec{\boldsymbol{E}}\cdot d\vec{\mathbf{A}} = \frac{Q_{free-enclosed}}{\epsilon_0} \qquad \int \epsilon\vec{\boldsymbol{E}}\cdot d\vec{\mathbf{A}} = Q_{free-enclosed} \qquad K \equiv \frac{\epsilon}{\epsilon_0} \qquad u = \frac{1}{2}K\epsilon_0 E^2 = \frac{1}{2}\epsilon E^2$$

Physical Constants and Units to Understand:

Volt: $1\ \mathrm{V} = 1\ \mathrm{J/C}$
Electric Field: $1\ \mathrm{N/C} = 1\ \mathrm{V/m}$
Capacitance (farads): $1\ \mathrm{F} = 1\ \mathrm{C/V}$

Topic 5 – Current and Resistance
Class 6

Reading: Chapter 25

Objectives:

1. Be able to define **current**, **current density** and **drift velocity**.
2. Be able to describe the operation of a resistor and calculate **resistance** based on **resistivity** and shape
3. Be able to use the simple (Drude) model of electrical conduction in terms of electron number density n and collision time τ
4. Be able to apply **Ohm's Law** both in terms of *E&J* and *V&I*
5. Be able to calculate **power** supplied to devices and power dissipated by resistors.
6. Be able to describe sources of **emf** and calculate their terminal voltage and power output (internal resistance)
7. Be able to use and identify standard circuit diagram symbols

Equations to Know from Memory:

Current: $I_{\text{av}} \equiv \frac{\Delta Q}{\Delta t}$ $\quad I = \lim_{\Delta t \to 0} I_{\text{av}} = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t}$ $\quad I = nqv_d A$ $\quad \rho = \frac{m}{ne^2 \tau}$

Resistance: $R \equiv \frac{\Delta V}{I}$ $\quad R = \rho \frac{L}{A}$ $\quad$ Ohm's Law: $\Delta V = IR$ $\quad \rho J = E$

Power Supplied: $\mathcal{P} = \Delta V\, I$ $\quad$ Power Dissipated by Resistor: $\mathcal{P} = I^2 R = \frac{\Delta V^2}{R}$

Physical Constants and Units to Understand:

Current (amps): $1\ \text{A} = 1\ \text{C/s}$
Resistance (ohms): $1\ \Omega = 1\ \text{V/A}$
Energy (kilowatt-hour): $1\ \text{kWh} = 3.60 \times 10^6\ \text{J}$

Topic 6 – DC Circuits
Class 7

Reading: Chapter 26

Objectives:

1. Be able to describe how to use voltmeters and ammeters in circuits
2. Be able to calculate the equivalent resistance for **series, parallel**, and complex combinations of resistors.
3. Be able to apply **Kirchhoff's Rules** to complex circuits.
4. Be able to describe transient currents in **RC circuits** and calculate time constants.
5. Be able to describe household circuits.

Equations to Know from Memory:

emf Sources – Terminal Voltage: $\Delta V = \varepsilon - Ir$ Power Output: $\mathcal{P} = I\,\mathcal{E}$

Resistors in Series: $R_{\text{eq}} = R_1 + R_2 + R_3 + \cdots$

Resistors in Parallel: $\dfrac{1}{R_{\text{eq}}} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \cdots$

Kirchhoff's Rules: $\sum I_{\text{in}} = \sum I_{\text{out}}\ (\text{junction rule})$ $\sum \Delta V = 0\ (\text{loop rule})$

Capacitor Charging: $\Delta V = \varepsilon\left(1 - e^{-t/RC}\right)$ $I = (\varepsilon / R)\, e^{-t/RC}$

Capacitor Discharging: $\Delta V = \varepsilon\, e^{-t/RC}$

Time Constant: $\tau = RC$

Topic 7 – Magnetic Fields and Forces
Class 8

Reading: Chapter 27

Objectives:

1. Be able to describe sources of **magnetic fields**.
2. Be able to draw **magnetic field lines** in simple cases.
3. Be able to calculate the **magnetic force** on moving charges and current-carrying wires.
4. Be able to calculate the **torque** on a current loop.
5. Be able to describe the motion of a charged particle in a magnetic field and explain quantitatively how a mass spectrometer works.
6. Recognize and explain quantitatively **magnetic dipoles,** $\vec{\tau}$

Equations to Know from Memory:

Magnetic Forces: $F = qvB\sin\theta$ (moving charge) $F = BIl\sin\theta$ (current carrying wire)

$\vec{F} = q\,\vec{v}\times\vec{B}$ (moving charge) $\vec{F} = I\ d\vec{l}\times\vec{B}$ (current carrying wire)

$$\Phi_B \equiv \int \vec{B}\cdot d\vec{A} = \int B\ \cos\theta\ dA$$ zero for a closed surface

Torque on current loop: $\tau = BIAN\sin\theta = \mu B\sin\theta$ Magnetic Moment: $\mu = IAN$

dipoles: $\vec{\tau} = \vec{\mu}\times\vec{B}$ $U = -\vec{\mu}\cdot\vec{B}$

Motion of Charged Particle in Magnetic Field: $r = \dfrac{mv}{qB}$

Physical Constants and Units to Understand:

Tesla (T): $1\ \mathrm{T} = 1\ \mathrm{Wb/m^2} = 1\ \dfrac{\mathrm{N}}{\mathrm{C\cdot m/s}} = 1\ \dfrac{\mathrm{N}}{\mathrm{A\cdot m}}$ Gauss (G): $1\ \mathrm{G} = 10^{-4}\ \mathrm{T}$

Permeability of Free Space: $\mu_0 = 4\pi\times10^{-7}\ \dfrac{\mathrm{T\cdot m}}{\mathrm{A}}$

Topic 8 – Sources of Magnetic Fields
Class 9

Reading: Chapter 28

Objectives:

1. Be able to describe sources of **magnetic fields**.
2. Be able to calculate the magnetic fields due to straight wires, loops, and solenoids.
3. Be able to calculate the magnetic force between parallel conductors.
4. When symmetry allows, use **Ampere's Law** to calculate magnetic fields
5. Be able to define: diamagnetic, paramagnetic, ferromagnetic.
6. Be able to define **magnetization** (*M*) and **relative permeability** K_m

Equations to Know from Memory:

$$d\vec{\boldsymbol{B}} = \frac{\mu_0}{4\pi}\frac{I\,d\vec{\boldsymbol{l}}\times\hat{\boldsymbol{r}}}{r^2} \qquad \int \vec{\boldsymbol{B}}\cdot d\vec{\boldsymbol{l}} = \mu_0 I_{enclosed}$$

Magnetic Fields: $B_{\text{wire}} = \frac{\mu_0 I}{2\pi r}$ $\quad B_{\text{loop}} = \frac{\mu_0 N I a^2}{2\left(x^2+a^2\right)^{\frac{3}{2}}}$ $\quad B_{\text{solenoid}} = \mu_0 n I \quad n = \frac{N}{l}$

Force between 2 Parallel Conductors: $\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}$

Physical Constants and Units to Understand:

Tesla (T): $1\ \text{T} = 1\ \text{Wb/m}^2 = 1\ \frac{\text{N}}{\text{C}\cdot\text{m/s}} = 1\ \frac{\text{N}}{\text{A}\cdot\text{m}}$ Gauss (G): $1\ \text{G} = 10^{-4}\ \text{T}$

Permeability of Free Space: $\mu_0 = 4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}$

Topic 9 – Electromagnetic Induction
Class 10

Reading: Chapter 29

Objectives:

1. Be able to define and calculate **magnetic flux**.
2. Be able to apply **Faraday's Law** of electromagnetic induction.
3. Be able to explain and apply **Lenz's Law**.
4. Be able to calculate motional emf.
5. Be able to explain the operation of electric generators and calculate their emf.

Equations to Know from Memory:

Magnetic Flux: $\Phi_B = BA\cos\theta$ $\quad\quad$ $\Phi_B \equiv \int \vec{B}\cdot d\vec{A}$

Faraday's Law of Induction: $\mathcal{E} = -N\dfrac{d\,\Phi_B}{d\,t}$

Motional emf: $|\mathcal{E}| = Blv$ $\quad\quad$ $\mathcal{E} = \int (\vec{v}\times\vec{B})\cdot d\vec{l}$

Electric Generators: $\varepsilon = NBA\,\omega\sin(\omega\,t)$

Faraday/Maxwell: $\int \vec{E}\cdot d\vec{l} = -\dfrac{d\Phi_B}{dt}$

Gauss/Maxwell: $\int \vec{E}\cdot d\vec{A} = \dfrac{Q_{enclosed}}{\epsilon_0}$ $\quad\quad$ Monopole/Maxwell: $\int \vec{B}\cdot d\vec{A} = 0$

Ampere/Maxwell: $\int \vec{B}\cdot d\vec{l} = \mu_0\left(I_{enclosed} + \epsilon_0\dfrac{d\,\Phi_E}{dt}\right)$ new displacement current

Topic 10 – Inductance
Class 12

<u>Reading</u>: Chapter 30

<u>Objectives</u>:

1. Define **mutual** (*M*) and **self** (*L*) **inductance**
2. Be able to calculate/approximate *M* and *L* in simple situations
3. Be able to calculate emf and current for **series RL circuits**.
4. Be able to describe and calculate the behavior of simple `switched-on' circuits involving inductors, capacitors, and resistors (*RL, RC, LC, LRC*)
5. Be able to define underdamped, critically damped, overdampled
6. Be able to calculate the **energy stored** in the magnetic field of an inductor.

Inductors: $\mathcal{E}_1 = -M \frac{dI_2}{dt}$ $\quad \mathcal{E}_2 = -M \frac{dI_1}{dt}$ $\quad \mathcal{E} = -L \frac{dI}{dt}$

$M = N_2 \frac{d\Phi_{B2}}{dI_1} = N_1 \frac{d\Phi_{B1}}{dI_2}$ $\quad L = N \frac{d\Phi_B}{dI}$

Transformers: $V_2 = \frac{N_2}{N_1} V_1$ $\quad L = \frac{\mu_0 N^2 A}{l}$

RL Circuits: $I = \frac{\varepsilon}{R}\left(1 - e^{-t/\tau}\right)$ $\quad \tau = L/R$

RC Circuits: $Q = C\,\mathcal{E}\left(1 - e^{-t/\tau}\right)$ $\quad I = \frac{\mathcal{E}}{R} e^{-t/\tau}$ $\quad \tau = RC$

LC Circuits: $\omega = \frac{1}{\sqrt{LC}}$ $\quad$ damping $Q = \frac{\omega}{2\beta} = \frac{\sqrt{L/C}}{R}$

LRC Circuits: $\omega' = \sqrt{\omega^2 - \beta^2}$ $\quad \beta = \frac{R}{2L}$ $\quad Q = A\,e^{-\beta t}\cos\left(\omega' t + \phi\right)$

Energy Stored in a Magnetic Field: $U = \frac{1}{2} L I^2$ $\quad u = \frac{B^2}{2\mu}$

<u>Units to Understand</u>:

Henry (H): $1\ \mathrm{H} = 1\ \mathrm{V \cdot s/A}$

Topic 11 – AC Circuits
Class 13

Reading: Chapter 31

Objectives:

1. Understand the relationship between **rms values** and maximum values.
2. Understand phasors as a way to display phase relationships: that V_L leads V_R & *I*, whereas V_C lags.
3. Be able to calculate capacitive and inductive **reactance**.
4. Be able to describe phase relationships for **RLC series** circuits.
5. Be able to calculate the **impedance** and **phase angle** for *RLC* circuits.
6. Be able to calculate the power dissipated in *RLC* circuits.
7. Be able to calculate the **resonant frequency** for an *RLC* circuit.
8. Know the basic characteristics of US household electrical service
9. Be able to explain the operation of transformers.

Equations to Know from Memory:

RMS values: $A_{\mathrm{rms}}=\frac{A_{\max}}{\sqrt{2}}$ Ohm's Law: $V_R=IR$

Capacitors: $X_C\equiv\frac{1}{2\pi fC}$ $V_{C,\mathrm{rms}}=I_{\mathrm{rms}}X_C$

Inductors: $X_L\equiv 2\pi fL$ $V_{L,\mathrm{rms}}=I_{\mathrm{rms}}X_L$

AC Circuits: $Z\equiv\sqrt{R^2+(X_L-X_C)^2}$ $V_{\mathrm{rms}}=I_{\mathrm{rms}}Z$ Phase Angle: $\tan\phi=\frac{X_L-X_C}{R}$

Power: $\mathcal{P}_{\mathrm{av}}=I_{\mathrm{rms}}V_{\mathrm{rms}}\cos\phi$ $\cos\phi=R/Z$

Resonance: $f_0=\frac{1}{2\pi\sqrt{LC}}$

Transformers: $V_2=\frac{N_2}{N_1}V_1$

Topic 12 – Electromagnetic Waves
Class 14

Reading: Chapter 32

Objectives:

1. Be able to describe **Maxwell's Equations**
2. Be able to describe light as a transverse electromagnetic wave.
3. Be able to describe various types of EM waves and sort them by frequency and/or wavelength: **electromagnetic spectrum**
4. Be able to describe energy and momentum in an electromagnetic wave and particularly the **Poynting vector**

Equations to Know from Memory:

speed of light $c=\frac{1}{\sqrt{\mu_0 \epsilon_0}}$ $\frac{v}{c}=\frac{1}{\sqrt{KK_m}}$

Properties of Electromagnetic Waves: $\frac{E}{B}=c$ $c=f\lambda$

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

Poynting: $\vec{S}=\frac{1}{\mu_0}\vec{E}\times\vec{B}$ momentum/pressure: $\frac{I}{c}$

Physical Constants to Know:

Speed of Light in vacuum: $c=3.00\times10^8\ \mathrm{m}/s$