KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

PHYSICS DEPARTMENT

PHYS 204 – Major I (TERM 241)

INSTRUCTOR: **Dr. Tariq Al-Abdullah**

Student Name:

Student ID:

- **Exam: 120 minutes**
- **Show all work. You must give sufficient justification for your answers. No credit will be given for answers that are unaccompanied by an explanation and/or clearly written calculations.**

Problem #	**Grade**
1-15	**/ 30**
16	**/ 4**
17	**/ 4**
18	**/ 4**
19	**/ 4**
20	**/ 4**
Total	**/ 50**

Good Luck!

Q1) A coil with an inductance of 2.00 H and a resistance of 10.0 Ω is suddenly connected to an ideal battery with ε = 100 V. At 0.100 s after the connection is made, find the energy stored in the magnetic field.

a) 3.30 J
b) 15.5 J
c) 4.51 J
d) 7.52 J
e) 10.9 J

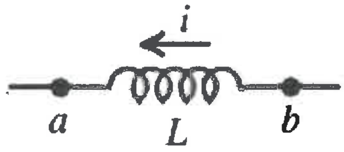
$$i = i_o\left(1 - e^{-t/\tau_L}\right) \; ; \; \tau_L = \frac{L}{R} = \frac{2}{10} = 0.2\,s$$

$$\Rightarrow i = \frac{100}{10}\left[1 - e^{-0.1/0.2}\right] = 3.93\,A$$

$$\Rightarrow U_B = \frac{1}{2} L i^2 = \frac{1}{2} \times 2 \times (3.93)^2 = 15.5\,J$$

Q2) The inductor in the **Figure** has inductance 0.260 H and carries a current in the direction shown. The current is changing at a constant rate. The potential between points a and b is V_{ab} = 1.04 V, with point a at higher potential. If the current at t = 0 is 12.0 A, what is the current at t = 2.00 s?

a) 20.0 A
b) 10.0 A
c) 14.0 A
d) 4.00 A
e) 8.00 A



$$\mathcal{E} = -L\frac{di}{dt}$$

$$\Rightarrow \left|\frac{di}{dt}\right| = \frac{\mathcal{E}}{L} = \frac{V_{ab}}{L} = \frac{1.04}{0.26}$$

$$= 4.0\,A/s \quad \text{and decreasing}$$

$$\frac{\Delta i}{\Delta t} = \frac{i_f - i_i}{2} = 4 = \left|\frac{i_f - 12}{2}\right| = 4$$

$$\Rightarrow i_f = 4.0\,A$$

Q3) If the inductance of an oscillating LC circuit is L = 1.05 H, find the natural frequency f when the maximum charge on the capacitor is 1.60 μC and the total energy is 140 μJ?

a) 5.55 kHz
b) 10.2 kHz
c) 14.8 kHz
d) 16.3 kHz
e) 7.36 kHz

$$U_E = \frac{Q^2}{2C} \Rightarrow C = \frac{Q^2}{2U_E} = \frac{(1.6)^2 \times 10^{-12}}{280 \times 10^{-6}}$$

$$\Rightarrow C = 9.14 \times 10^{-9}\,F$$

$$\omega = \frac{1}{\sqrt{LC}} = 2\pi f$$

$$\Rightarrow f = \frac{1}{2\pi\sqrt{LC}} = 1.63\,kHz$$

Q4) A series *RLC* circuit has a driven frequency of 8.0 kHz, an impedance of 2.5 kΩ, and a phase constant of 37°.Find the resistance for this circuit?

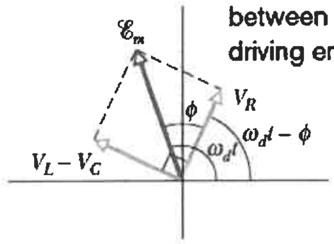
a) 2.0 kΩ
b) 3.5 kΩ
c) 1.5 kΩ
d) 1.8 kΩ
e) 1.2 kΩ

$\cos\phi = \frac{R}{Z}$

$R = Z\cos\phi$

$= 2.5\times10^3 \cos 37^\circ$

$= 2.0\ k\Omega$



This ϕ is the angle between I and the driving emf.

Q5) An air conditioner connected to a 120 V rms ac line is equivalent to a 12.0 Ω resistance and a 1.30 Ω inductive reactance in series. Calculate the average rate at which energy is supplied to the appliance.

a) 2.16×10^3 W
b) 4.44×10^3 W
c) 1.19×10^3 W
d) 1.77×10^3 W
e) 1.68×10^3 W

$P_{avg} = \frac{\mathcal{E}_{rms}^2 R}{Z^2}$

$Z = \sqrt{R^2 + X_L^2} = \sqrt{12^2 + 1.3^2} = 12.1\ \Omega$

$\Rightarrow P_{avg} = \frac{120^2 * 12}{(12.1)^2} = 1.19\times10^3\ W$

Q6) A parallel-plate capacitor with circular plates of radius 0.10 m is being discharged. A circular loop of radius 0.20 m is concentric with the capacitor and halfway between the plates. The displacement current through the loop is 2.0 A. At what rate is the electric field between the plates changing?

a) 2.8×10^{12} V/m.s
b) 4.5×10^{12} V/m.s
c) 3.6×10^{12} V/m.s
d) 5.9×10^{12} V/m.s
e) 7.2×10^{12} V/m.s

$\oint \vec{B}\cdot d\vec{s} = \mu_0 i_d = \mu_0 \epsilon_0 A \frac{dE}{dt}$

$\Rightarrow \frac{dE}{dt} = \frac{i_d}{\epsilon_0 A} = \frac{2}{8.85\times10^{-12}\times\pi\times0.1^2}$

$= 7.2\times10^{12}\ \frac{V}{m\cdot s}$

Q7) A 0.50 T magnetic field is applied to a paramagnetic gas whose atoms have an intrinsic magnetic dipole moment of 1.0×10^{-23} J/T. At what temperature will the mean kinetic energy of translation of the atoms equal the energy required to reverse such a dipole end for end in this magnetic field?

a) 0.13 K
b) 0.27 K
c) 0.39 K
d) 0.48 K
e) 0.56 K

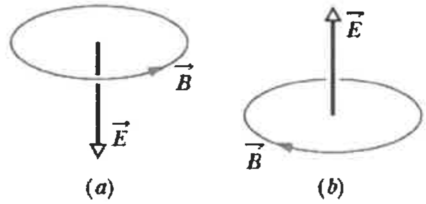
$$\Delta U_B = K$$

$$\mu B[\cos 0 - \cos 180] = \frac{3}{2} kT$$

$$T = \frac{4\mu B}{3k} = \frac{4 \times 0.5 \times 10^{-23}}{3 \times 1.38 \times 10^{-23}} = 0.48\ K$$

Q8) The figure shows, in two situations, an electric field vector and an induced magnetic field line. In each, is the magnitude of $\vec{E}$ increasing or decreasing?

a) *a*, decreasing; *b*, increasing
b) *a*, decreasing; *b*, decreasing
c) *a*, increasing; *b*, decreasing
d) *a*, increasing; *b*, increasing
e) none of the above



Q9) What is the intensity of a traveling plane electromagnetic wave if B_m is 1.0×10^{-4} T?

a) 4.9×10^6 W/m^2
b) 3.5×10^6 W/m^2
c) $\boxed{1.2 \times 10^6 \text{ W/m}^2}$
d) 7.0×10^6 W/m^2
e) 0.81×10^6 W/m^2

$$S = \frac{1}{\mu_0} \vec{E} \times \vec{B}$$

$$I = S_{avg} = \frac{EB}{2\mu_0} = \frac{B^2}{2\mu_0} c$$

$$\Rightarrow \cancel{B = \sqrt{\frac{2\mu_0 I}{c}} = \sqrt{2 \times 4\pi \times 10^{-7} \times}}$$

$$= \frac{(10^{-4})^2 \times 3 \times 10^8}{2 \times 4\pi \times 10^{-7}} = 1.2 \times 10^6\ W/m^2$$

Q10) What inductance must be connected to a 17.0 pF capacitor in an oscillator capable of generating 550 nm electromagnetic waves?

a) 6.98×10^{-21} H
b) 4.04×10^{-21} H
c) 5.00×10^{-21} H
d) 3.22×10^{-21} H
e) 5.79×10^{-21} H

$$c = \lambda f = \frac{\lambda}{2\pi\sqrt{LC}}$$

$$c^2 = \frac{\lambda^2}{4\pi^2 LC}$$

$$\Rightarrow L = \frac{\lambda^2}{4\pi^2 c^2 C} = 5.01 \times 10^{-21}\ H$$

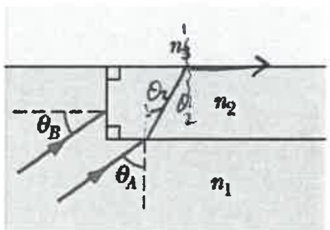
Q11) In the figure, light from ray ***A*** refracts from material **1** ($n_1 = 1.60$) into a thin layer of material **2** ($n_2 = 1.80$), crosses that layer, and is then incident at the critical angle on the interface between materials **2** and **3** ($n_3 = 1.30$). What is the value of incident angle θ_A?

a) 45.0º
b) 60.2º
c) 25.7º
d) 37.1º
e) 54.3º

$$n_1 \sin\theta_A = n_2 \sin\theta_2 = n_3 \sin\frac{\pi}{2}$$

$$\sin\theta_A = \frac{n_3}{n_1}$$

$$\theta_A = \sin^{-1}\left(\frac{1.3}{1.6}\right) = 54.3^\circ$$



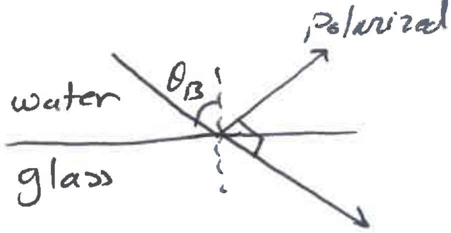
Q12) Light that is traveling in water (with an index of refraction of 1.33) is incident on a plate of glass (with index of refraction 1.53). At what angle of incidence does the reflected light end up fully polarized?

a) 49.0º
b) 41.0º
c) 53.0º
d) 37.0º
e) 30.0º

$$\tan\theta_B = \frac{n_2}{n_1}$$

$$\theta_B = \tan^{-1}\left(\frac{1.53}{1.33}\right)$$

$$= 49.0^\circ$$



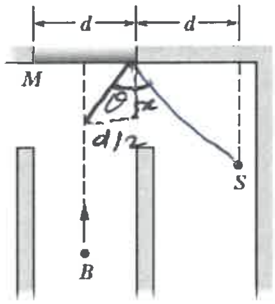
Q13) The figure shows an overhead view of a corridor with a plane mirror M mounted at one end. A man B sneaks along the corridor directly toward the center of the mirror. If d = 4.0 m, how far from the mirror will he be when the security guard S can first see him in the mirror?

a) 2.0 m
b) 1.5 m
c) 2.5 m
d) 3.0 m
e) 1.0 m

$\theta = 45^\circ$

$\tan\theta = \dfrac{d/2}{x}$

$\Rightarrow x = \dfrac{d}{2\tan\theta} = \dfrac{4}{2} = 2\,m$



Q14) A convex lens is to be made of glass with an index of refraction of 1.5. One surface is to have twice the radius of curvature of the other and the focal length is to be 60 mm. What is the smaller radius?

a) 45 mm
b) 15 mm
c) 30 mm
d) 60 mm
e) 50 mm

$\dfrac{1}{f} = (n-1)\left[\dfrac{1}{r_2} - \dfrac{1}{r_1}\right]$ $\quad r_2 = -2r_1$

$= (n-1)\left[\dfrac{1}{2r_1} - \dfrac{1}{r_1}\right] = (n-1)\left(\dfrac{1}{2r_1} + \dfrac{1}{r_1}\right)$

$\dfrac{1}{60} = 0.5 \times \dfrac{3}{2}\,\dfrac{1}{r_1}$

$\Rightarrow r_1 = \dfrac{0.5 \times 3 \times 60}{2} = 45\,mm$

Q15) The distance between the eyepiece and the objective lens in a certain compound microscope is 23.0 cm. The focal length of the eyepiece is 2.50 cm and that of the objective is 0.400 cm. What is the overall magnification of the microscope?

a) −624
b) 457
c) −503
d) 301
e) −378

$L = f_{obj} + S + f_{eye} = 23\,cm$

$f_{eye} = 2.5\,cm$

$\Rightarrow I = L - f_{eye} = f_{obj} + S = 23 - 2.5 = 20.5\,cm$

$S = 20.5 - 0.4 = 20.1\,cm$

$M = -\dfrac{S}{f_{obj}}\,\dfrac{25}{f_{eye}} = -\dfrac{20.1}{0.4}\,\dfrac{25}{2.5} = -503$

Q16) Two solenoids are part of the spark coil of an automobile. When the current in one solenoid falls from 6.0 A to zero in 2.5 ms, an emf of 30 kV is induced in the other solenoid. What is the mutual inductance M of the solenoids?

$$\mathcal{E}_2 = -M \frac{di_1}{dt}$$

$$M = \frac{\mathcal{E}_2}{\left|\frac{\Delta i}{\Delta t}\right|} = \frac{30 \times 10^3}{\frac{6}{2.5 \times 10^{-3}}} = 12.5 \text{ H}$$

Q17) An *ac* generator has emf $\mathcal{E} = \mathcal{E}_m \sin \omega_d t$, with $\mathcal{E}_m = 25.0$ V and $\omega_d = 377$ rad/s. It is connected to a 12.7 H inductor. (a) What is the maximum value of the current? (b) When the emf of the generator is -12.5 V and increasing in magnitude, what is the current?

simple circuit $\mathcal{E}$ & ~~H~~ L only

(a) $$I = \frac{\mathcal{E}_m}{X_L} = \frac{\mathcal{E}_m}{\omega_d L} = \frac{25}{377 \times 12.7} = 5.22 \times 10^{-3} A$$

(b) $\mathcal{E} = -12.5$

$$-12.5 = 25 \sin \omega_d t \Rightarrow \sin \omega_d t = -\frac{1}{2} \Rightarrow \omega_d t = \frac{7\pi}{6}, \frac{11\pi}{6}$$

increasing $\mathcal{E} \Rightarrow$ becomes more negative

$\therefore$ ~~dosw~~

$$i = I \sin(\omega_d t - \tfrac{\pi}{2}) = 5.22 \times 10^{-3} \sin\left(\frac{7\pi}{6} - \frac{\pi}{2}\right)$$

$$\text{or } \sin\left(\frac{11\pi}{6} - \frac{\pi}{2}\right)$$

$$= 5.22 \times 10^{-3} \times \frac{\sqrt{3}}{2} = 4.51 \times 10^{-3} A$$

Q18) Suppose that a parallel-plate capacitor has circular plates with radius $R = 30$ mm and a plate separation of 5.0 mm. Suppose also that a sinusoidal potential difference with a maximum value of 150 V and a frequency of 60 Hz is applied across the plates; that is,

$$V = (150\ \text{V})\ \sin[2\pi(60\ \text{Hz})t].$$

Find $B_{max}(R)$, the maximum value of the induced magnetic field that occurs at $r = R$.

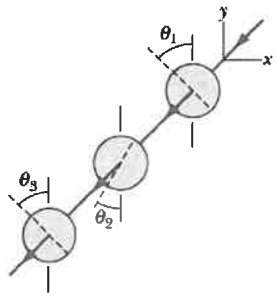
$$\oint \vec{B} \cdot d\vec{s} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt} = \mu_0 \epsilon_0 A \frac{dE}{dt}$$

$$B_{max}\, 2\pi R = \mu_0 \epsilon_0 A \frac{1}{d} \frac{dV}{dt} = \mu_0 \epsilon_0 \frac{\pi R^2}{d} \frac{dV}{dt}$$

$$\Rightarrow B_{max} = \frac{\mu_0 \epsilon_0 R}{2d} V_{max}\, 2\pi(60) \underbrace{\cos\omega t}_{=1}$$

$$= 1.9 \times 10^{-12}\ T$$

Q19) In the figure, initially unpolarized light is sent into a system of three polarizing sheets whose polarizing directions make angles of $\theta_1 = 40°$, $\theta_2 = 20°$, and $\theta_3 = 40°$ with the direction of the y axis. What percentage of the light's initial intensity is transmitted by the system?



$$I = I_0 \cos^2\theta$$

unpolarized light $\Rightarrow I_1 = \frac{1}{2} I_0$

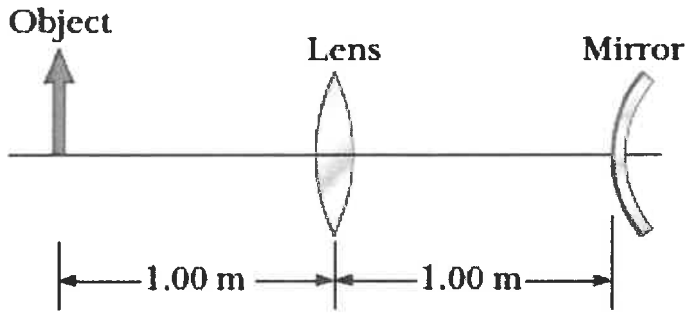
$$I_2 = I_1 \cos^2(\theta_1 + \theta_2) = I_1 \cos^2 60°$$

$$I_3 = I_2 \cos^2(\theta_2 + \theta_3) = I_2 \cos^2 60°$$

$$\Rightarrow I_3 = \frac{1}{2} I_0 \cos^4 60° = 3.1 \times 10^{-2}\ I_0$$

$$\Rightarrow \frac{I_3}{I_0} = 3.1 \times 10^{-2}$$ or 3.1 % transmitted intensity

Q20) The lens and mirror in the Figure are separated by $d = 1.00$ m and have focal lengths of 80.0 cm and 50.0 cm, respectively. An object is placed $p = 1.00$ m to the left of the lens as shown. (a) Locate the final image, formed by light that has gone through the lens twice. (b) Determine the overall magnification of the image



First image From the lens

$$\frac{1}{p} + \frac{1}{i_1} = \frac{1}{f} \Rightarrow \frac{1}{i_1} = \frac{1}{f} - \frac{1}{p} = \frac{1}{0.8} - 1 = \frac{1}{4}$$

$$\Rightarrow i_1 = 4 \text{ m} \quad \text{or} \quad 400 \text{ cm}$$

* The new object & the mirror

$$p_2 = 100 - 400 = -300 \text{ cm}$$

$$\frac{1}{p_2} + \frac{1}{i_2} = -\frac{1}{50} \Rightarrow \frac{1}{i_2} = -\frac{1}{50} + \frac{1}{300} = -\frac{1}{60}$$

$$\text{or} \quad i_2 = -60 \text{ cm}$$

* The p_3 object and the lens again:

$$p_3 = 100 - i_2 = 100 - -60 = 160 \text{ cm}$$

$$\frac{1}{p_3} + \frac{1}{i_3} = \frac{1}{f_L} \Rightarrow \frac{1}{i_3} = \frac{1}{f_L} - \frac{1}{p_3} = \frac{1}{80} - \frac{1}{160} = \frac{1}{160}$$

$$\Rightarrow i_3 = 160 \text{ cm} \quad \text{to the left of the lens}$$

$$M = \left(-\frac{i_1}{p_1}\right)\left(-\frac{i_2}{p_2}\right)\left(-\frac{i_3}{p_3}\right) = \left(-\frac{400}{100}\right)\left(-\frac{60}{300}\right)\left(-\frac{160}{160}\right)$$

$$= -0.8$$

Formula Sheet

Ch30

$$\mathcal{E} = \oint \vec{E} \cdot d\vec{s},$$

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

$$L = \frac{N\Phi_B}{i}$$

$$\frac{L}{l} = \mu_0 n^2 A$$

$$\mathcal{E}_L = -L\frac{di}{dt}$$

$$i = \frac{\mathcal{E}}{R}(1 - e^{-t/\tau_L})$$

$$i = i_0 e^{-t/\tau_L}$$

$$U_B = \tfrac{1}{2}Li^2$$

$$\mathcal{E}_2 = -M\frac{di_1}{dt}$$

Ch31

$$q = Q\cos(\omega t + \phi)$$

$$q = Qe^{-Rt/2L}\cos(\omega' t + \phi)$$

$$\omega' = \sqrt{\omega^2 - (R/2L)^2}.$$

$$\mathcal{E} = \mathcal{E}_m \sin \omega_d t.$$

$$i = I\sin(\omega_d t - \phi),$$

$$I = \frac{\mathcal{E}_m}{\sqrt{R^2 + (X_L - X_C)^2}}$$

$$\tan\phi = \frac{X_L - X_C}{R}$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$P_{avg} = I_{rms}^2 R = \mathcal{E}_{rms} I_{rms}\cos\phi.$$

Ch32

$$\oint \vec{B} \cdot d\vec{s} = \mu_0\varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$

$$M = C\frac{B_{ext}}{T}.$$

Ch33

$$E = E_m \sin(kx - \omega t)$$

$$B = B_m \sin(kx - \omega t),$$

$$c = \frac{E}{B} = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$$

$$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B}.$$

$$I = \frac{P_s}{4\pi r^2}$$

$$I = I_0\cos^2\theta.$$

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

$$\theta_c = \sin^{-1}\frac{n_2}{n_1}.$$

$$\theta_B = \tan^{-1}\frac{n_2}{n_1}$$

Ch34

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f} = \frac{2}{r},$$

$$m = -\frac{i}{p}.$$

$$|m| = \frac{h'}{h}$$

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right),$$

$$m_\theta = \frac{25\text{ cm}}{f}$$

$$M = mm_\theta = -\frac{s}{f_{ob}}\frac{25\text{ cm}}{f_{ey}}$$

$y(x,t) = y_m \sin(kx \pm \omega t)$	
$k = \dfrac{2\pi}{\lambda}$	$\omega = \dfrac{2\pi}{T} = 2\pi f$
$v = \sqrt{\tau/\mu}$	$P_{avg} = \dfrac{1}{2}\mu v \omega^2 y_m^2$
$y'(x,t) = [2y_m \cos\frac{1}{2}\phi]\sin(kx - \omega t + \phi/2)$	
$y'(x,t) = [2y_m \sin kx]\cos\omega t$	
$f = \dfrac{v}{\lambda} = n\dfrac{v}{2L} \quad n = 1,2,3,....$	
$s = s_m \cos(kx - \omega t)$	
$\Delta p = \Delta p_m \sin(kx - \omega t)$	
$v = \sqrt{B/\rho}$	$\Delta p_m = \rho v \omega s_m$
$\Delta L/\lambda = 1,2,3,4,...$	$\Delta L/\lambda = 0.5, 1.5, 2.5, ...$
$\phi = \dfrac{\Delta L}{\lambda} 2\pi$	$I = \dfrac{P_s}{4\pi r^2}$
$I = \dfrac{1}{2}\rho v \omega^2 s_m^2$	$\beta = (10 dB)\log\dfrac{I}{I_o}$
$f' = f\dfrac{v \pm v_D}{v \pm v_S}$	$f = n\dfrac{v}{4L}; n = 1,3,5,...$
$T_C = T - 273$	$T_F = \dfrac{9}{5}T_C + 32^o$
$\Delta L = L\alpha\Delta T$	$\Delta V = V\beta\Delta T; \beta = 3\alpha$
$Q = Lm$	$Q = cm\Delta T$
$\Delta E_{int} = Q - W$	$W = \int dW = \int_{V_i}^{V_f} PdV$
$P_{rad} = \sigma\varepsilon A T^4$	$P_{abs} = \sigma\varepsilon A T_{env}^4$
$P_{cond} = \dfrac{Q}{t} = kA\dfrac{T_H - T_C}{L}$	
$PV = nRT = NkT$	$W = nRT\ln\dfrac{V_f}{V_i}$
$v_{rms} = \sqrt{\dfrac{3RT}{M}}$	$K_{avg} = \dfrac{3}{2}kT$
$C_V = \dfrac{Q}{n\Delta T}$	$C_P = \dfrac{Q}{n\Delta T}$
$C_P = C_V + R$ $C_V = \dfrac{3}{2}R;\ \gamma = \dfrac{C_p}{C_V}$	$\Delta E_{int} = nC_V\Delta T$ $PV^\gamma = Constant$
$TV^{\gamma-1} = Constant$	$\Delta S = \dfrac{Q}{T}$

$\Delta S = \int_i^f \dfrac{dQ}{T}$	$\Delta S = mc\ln\left(\dfrac{T_f}{T_i}\right)$
$\Delta S = nR\ln\left(\dfrac{V_f}{V_i}\right) + nc_V\ln\left(\dfrac{T_f}{T_i}\right)$	
$W = \lvert Q_H\rvert - \lvert Q_L\rvert$	$\dfrac{\lvert Q_H\rvert}{T_H} = \dfrac{\lvert Q_L\rvert}{T_L}$
$\varepsilon = \dfrac{\lvert W\rvert}{\lvert Q_H\rvert}$	$K = \dfrac{\lvert Q_L\rvert}{\lvert W\rvert}$
$\varepsilon_c = 1 - \dfrac{\lvert Q_L\rvert}{\lvert Q_H\rvert} = 1 - \dfrac{T_L}{T_H}$	
$K_c = \dfrac{\lvert Q_L\rvert}{\lvert Q_H\rvert - \lvert Q_L\rvert} = \dfrac{T_L}{T_H - T_L}$	
$F = \dfrac{1}{4\pi\varepsilon_o}\dfrac{\lvert q_1\rvert\lvert q_2\rvert}{r^2}$	$U = -\vec{p}.\vec{E}$
$E = \dfrac{1}{4\pi\varepsilon_o}\dfrac{\lvert q\rvert}{r^2}$	$E = \dfrac{\sigma}{2\varepsilon_o}$
$\Phi = \oint \vec{E}.d\vec{A}$	$\vec{E} = \dfrac{\vec{F}}{q_o}$
$E = \left(\dfrac{q}{4\pi\varepsilon_o R^3}\right)r$	$\varepsilon_o\Phi_{net} = q_{enc}$
$\vec{\tau} = \vec{p}\times\vec{E}$ $U = -\vec{p}\cdot\vec{E}$	$E = \dfrac{\sigma}{\varepsilon_o}$
$\Delta U = q\Delta V$	$E = \dfrac{\lambda}{2\pi\varepsilon_o r}$
$V_f - V_i = -\int_i^f \vec{E}\cdot d\vec{s}$	$\Delta U = -W$
$V = \sum_{i=1}^{n} V_i = \dfrac{1}{4\pi\varepsilon_o}\sum_{i=1}^{n}\dfrac{q_i}{r_i}$	$V = \dfrac{1}{4\pi\varepsilon_o}\dfrac{q}{r}$
$E_x = -\dfrac{\partial V}{\partial x}; E_y = -\dfrac{\partial V}{\partial y}; E_z = -\dfrac{\partial V}{\partial z}$	
$U = W = \dfrac{1}{4\pi\varepsilon_o}\dfrac{q_1 q_2}{r}$	$q = CV$
$U = \dfrac{q^2}{2C} = \dfrac{1}{2}CV^2$	$u = \dfrac{1}{2}\varepsilon_o E^2$
$C = 2\pi\varepsilon_o\dfrac{L}{\ln(b/a)}$	$C = \dfrac{\varepsilon_o A}{d}$
$C = 4\pi\varepsilon_o\dfrac{ab}{b-a}$	$C = \kappa C_{air}$

$$v = v_o + at;\quad \Delta x = v_o t + \frac{1}{2}at^2$$

$i = \dfrac{dq}{dt}$	$J = (ne)v_d$	$i = \int \vec{J}\cdot d\vec{A}$
$\rho = \dfrac{1}{\sigma} = \dfrac{E}{J}$	$P = iV$	$R = \dfrac{V}{i} = \rho\dfrac{L}{A}$

$$\rho - \rho_o = \rho_o\alpha(T - T_o)$$

$q = C\varepsilon\left(1 - e^{-t/RC}\right)$	$i = \left(\dfrac{\varepsilon}{R}\right)e^{-t/RC}$
$q = q_o e^{-t/RC}$	$i = -\left(\dfrac{q_o}{RC}\right)e^{-t/RC}$
$\vec{F}_B = q\left(\vec{v}\times\vec{B}\right)$	$\vec{\tau} = \vec{\mu}\times\vec{B}$
$\vec{F}_B = i\left(\vec{L}\times\vec{B}\right)$	$U(\theta) = -\vec{\mu}\cdot\vec{B}$
$B = \dfrac{\mu_o i\phi}{4\pi R}$	$d\vec{B} = \dfrac{\mu_o}{4\pi}\dfrac{i\left(d\vec{s}\times\hat{r}\right)}{r^2}$
$B = \dfrac{\mu_o i}{2\pi R}$	$\oint \vec{B}.d\vec{s} = \mu_o i_{enc}$
$B = \mu_o ni$	$F_{ba} = \dfrac{\mu_o L i_a i_b}{2\pi d}$
$P = \dfrac{B^2L^2v^2}{R}$	$\Phi_{net} = \int \vec{B}\cdot d\vec{A}$
$\varepsilon = -N\dfrac{d\Phi_B}{dt}$	$\varepsilon = BLv$

CONSTANTS

$\varepsilon_o = 8.854\times10^{-12}\ C^2/N\cdot m^2$	
$N_A = 6.022\times10^{23}$ molecules / mole	
$\sigma = 5.6704\times10^{-8}\ W/m^2\cdot K^4$	
$1\,atm = 1.01\times10^5\ N/m^2$	
$1\,eV = 1.602\times10^{-19}\ J$	$v_{air} = 343\ m/s$
$\lvert e\rvert = 1.602\times10^{-19}\ C$	$I_o = 10^{-12}\ W/m^2$
$\mu_o = 4\pi\times10^{-7}\ T\cdot m/A$	$m_e = 9.11\times10^{-31}\ kg$
$m_p = 1.673\times10^{-27}\ kg$	$g = 9.8\ m/s^2$
$R = 8.314\ J/mole.K$	$1\ L = 10^{-3}\ m^3$
$k = 1.381\times10^{-23}\ J/K$	$1\,cal = 4.1868\ J$

FOR WATER

$c = 4187\ J/kg.K$

$L_V = 2256\ kJ/kg \qquad L_F = 333\ kJ/kg$

PREFIXES

$M = mega = 10^6$	$k = kilo = 10^3$
$m = milli = 10^{-3}$	$\mu = micro = 10^{-6}$
$n = nano = 10^{-9}$	$p = pico = 10^{-12}$
$G = giga = 10^9$	$T = tera = 10^{12}$