Last Name:________________First Name_________________NetID_______________
Discussion Section:________Discussion TA Name:______________________________

Instructions—
Turn off your cell phone and put it away.
Keep your calculator on your own desk. Calculators may not be shared.
This is a closed book exam. You have ninety (90) minutes to complete it.

1. Use a #2 pencil; do **not** use a mechanical pencil or a pen. Fill in completely (until there is no white space visible) the circle for each intended input – both on the identification side of your answer sheet and on the side on which you mark your answers. If you decide to change an answer, erase vigorously; the scanner sometimes registers incompletely erased marks as intended answers; this can adversely affect your grade. Light marks or marks extending outside the circle may be read improperly by the scanner.

2. Print your last name in the **YOUR LAST NAME** boxes on your answer sheet and print the first letter of your first name in the **FIRST NAME INI** box. Mark (as described above) the corresponding circle below each of these letters.

3. Print **YOUR LAST NAME** in the designated spaces at the *left* side of the answer sheet, then mark the corresponding circle below each letter. Do the same for your **FIRST NAME INITIAL**.

4. You may find the version of **this Exam Booklet at the top of page 2**. Mark the **version** circle in the **TEST FORM** box in the bottom right of your answer sheet. **DO THIS NOW!**

5. Do not write in or mark the circles in any of the other boxes (STUDENT NUMBER, DATE, SECTION, SCORES, SPECIAL CODE).

6. Sign your name **(DO NOT PRINT)** on the **STUDENT SIGNATURE** line.

7. On the **SECTION** line, print your **DISCUSSION SECTION**. You need not fill in the COURSE or INSTRUCTOR lines.

Before starting work, check to make sure that your test booklet is complete. You should have 11 ***numbered pages*** *plus two Formula Sheets at the end.*

Academic Integrity—**Giving assistance to or receiving assistance from another student or using unauthorized materials during a University Examination can be grounds for disciplinary action, up to and including expulsion.**

This Exam Booklet is Version A. Mark the **A** circle in the **TEST FORM** box in the bottom right of your answer sheet. **DO THIS NOW!**

Exam Grading Policy—

The exam is worth a total of 102 points, composed of two types of questions.

MC5: *multiple-choice-five-answer questions, each worth 6 points.*
Partial credit will be granted as follows.

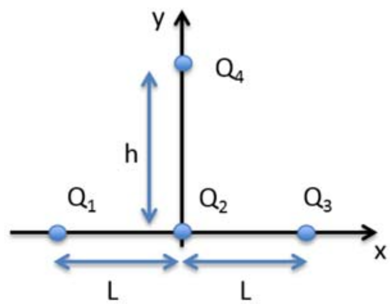
(a) If you mark only one answer and it is the correct answer,
you earn **6** points.
(b) If you mark *two* answers, one of which is the correct answer,
you earn **3** points.
(c) If you mark *three* answers, one of which is the correct answer,
you earn **2** points.
(d) If you mark no answers, or more than *three*, you earn 0 points.

MC3: *multiple-choice-three-answer questions, each worth 3 points.*
No partial credit.

(a) If you mark only one answer and it is the correct answer,
you earn **3** points.
(b) If you mark a wrong answer or no answers, you earn **0** points.

The next two questions pertain to the situation described below.

Three point charges Q_1=5 μC, Q_2=-7.5 μC and Q_3=5 μC are placed a distance L=1.3 meter apart on the x-axis at points (-L, 0), (0,0), and (L, 0) as shown in the figure. A fourth charge Q_4=-7.5 μC is placed at a position (0, h) where h = 2.6 m.



1) What is x-component of the force on Q_4 due to the charges Q_1, Q_2, and Q_3?

a. F_{Q4x} = 0.0749 N
b. F_{Q4x} = 0.0392 N
c. F_{Q4x} = Zero
d. F_{Q4x} = -0.111 N
e. F_{Q4x} = -0.0357 N

2) What is y-component of the force on Q_4 due to the charges Q_1, Q_2, and Q_3?

a. F_{Q4y} = 0.0749 N
b. F_{Q4y} = -0.00499 N
c. F_{Q4y} = -0.146 N
d. F_{Q4y} = Zero
e. F_{Q4y} = 0.00344 N

The next two questions pertain to the situation described below.

Two conducting spheres of radii r_1 = 20 mm and r_2 = 5 mm are charged with q_1 = 0.4 μC and q_2 = 0.12 μC respectively. The spheres are separated by a large distance.

3) What is the potential difference between the surfaces of the two spheres?

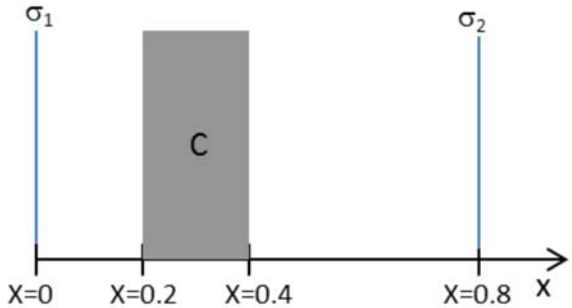
a. 3.6×10^4 Volts
b. 2.16×10^5 Volts
c. 1.8×10^5 Volts

4) If the spheres are connected by a thin conducting wire, in which direction (if any) would positive charge flow?

a. from sphere 1 to sphere 2
b. no net charge is transferred between the two spheres
c. from sphere 2 to sphere 1

The next two questions pertain to the situation described below.

Two infinite nonconducting sheets of charge and one infinite conducting slab are placed perpendicular to the x direction as shown in the following figure. The conducting slab is electrically neutral and labeled C. The charge densities on the two sheets of charge are σ_1 = +5 μC/m^2 and σ_2 = -9.5 μC/m^2.



5) The x-component of the electric field at x = 0.9 is:

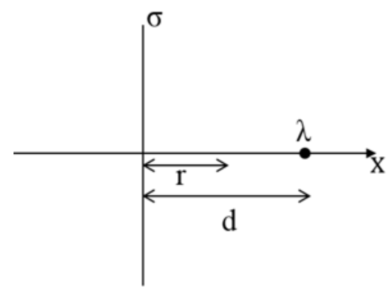
a. E_x = -0.536 × 10^6 V/m
b. E_x =0.536 × 10^6 V/m
c. E_x =-0.254 × 10^6 V/m

6) The induced charge density on the left side of the conductor (i.e. at x=0.2) is

a. σ_L = -7.25 μC/m^2
b. σ_L = -2.5 μC/m^2
c. σ_L = -5 μC/m^2
d. σ_L = -2.25 μC/m^2
e. σ_L = -14.5 μC/m^2

The next three questions pertain to the situation described below.

An infinite sheet with charge density per unit area σ is placed along the y axis at x=0. An infinite line of charge with charge density per unit length λ is located at x=d and y=0 and oriented in the z direction (out of page) as shown in the figure.



7) What is the x component of the electric field **due ONLY to the infinite line of charge** at the point on the x axis a distance r to the right of the plane, as shown in the figure?

a. $E_x = \frac{\lambda}{2\pi\epsilon_0 r}$
b. $E_x = \frac{\lambda}{4\pi\epsilon_0 r^2}$
c. $E_x = \frac{-\lambda}{2\pi\epsilon_0 r}$
d. $E_x = \frac{\lambda}{2\pi\epsilon_0 (d-r)}$
e. $E_x = \frac{-\lambda}{2\pi\epsilon_0 (d-r)}$

8) You are told that there is a point on the x axis between the charged plane and the line of charge (0 < r < d) where the electric field is zero. What can you conclude about the signs of λ and σ?

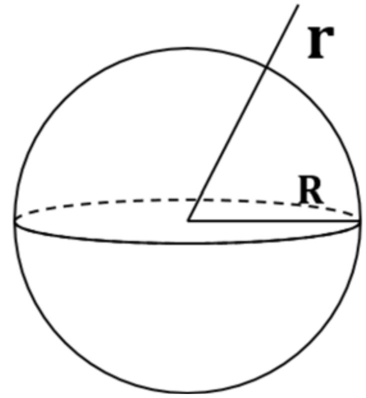
a. They are both negative.
b. The are both positive.
c. They have the opposite sign.
d. Nothing.
e. They have the same sign.

9) Which expression gives the position along the x axis between the line of charge and the charged plane at which the electric field is zero?

a. $r = \frac{\lambda}{\pi\sigma}$
b. $r = d + \frac{\lambda}{\pi\sigma}$
c. $r = d - \frac{\lambda}{\pi\sigma}$

The next three questions pertain to the situation described below.

An insulating sphere of radius R carries a charge density per unit volume ρ as shown in the figure.



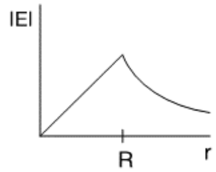
10) What is the magnitude of the electric field at a distance r > R from the center of the sphere?

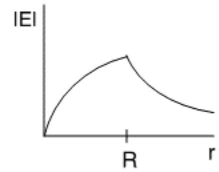
a. $|E| = \frac{1}{3\rho\epsilon_0}\frac{R^3}{r^2}$
b. $|E| = \frac{1}{3\epsilon_0}\frac{\rho R^3}{r^2}$
c. $|E| = \frac{1}{4\pi\epsilon_0}\frac{\rho R^3}{r^2}$
d. $|E| = \frac{1}{4\pi\epsilon_0}\frac{\rho}{r^2}$
e. $|E| = \frac{1}{3\epsilon_0}\frac{\rho R^2}{r}$

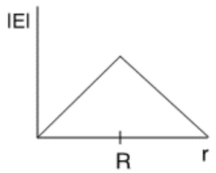
11) What is the magnitude of the electric field at a distance r < R from the center of the sphere?

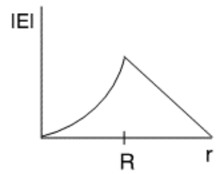
a. $|E| = \frac{\rho R}{3\epsilon_0}$
b. $|E| = \frac{\rho r^2}{3\epsilon_0}$
c. $|E| = \frac{\rho r}{6\epsilon_0}$
d. $|E| = \frac{\rho R}{6\epsilon_0}$
e. $|E| = \frac{\rho r}{3\epsilon_0}$

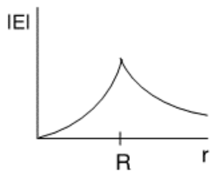
12) Which of the following best describes the magnitude of the |E| field as a function of the distance from the center of the sphere r?

a) 

d) 

b) 

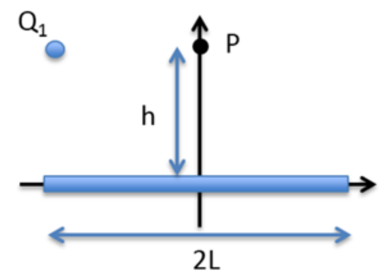
e) 

c) 

a.
b.
c.
d.
e.

The next three questions pertain to the situation described below.

A charge Q_1 is placed at the point (-L, h) and a rod of length 2 m and total charge charge Q_{rod} = 18 μC distributed uniformly along its length, is placed with its ends at (-L, 0) and (0, L) as shown in the figure.



13) What is the linear charge density of the rod?

a. $\lambda = 9\ \mu$C/m
b. $\lambda = 36\ \mu$C /m
c. $\lambda = 4.5\ \mu$C/m

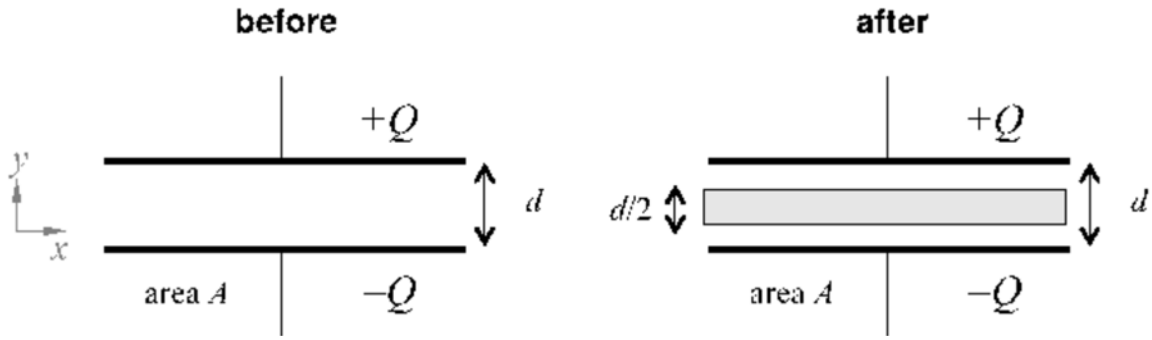
14) Which expression gives the electric field at the point **P** = (0, h) due to the point charge and line of charge?

a. $\vec{E} = k\lambda \int_{-L}^{L} \frac{dx}{(x^2+h^2)} \hat{y}$
b. $\vec{E} = \frac{kQ_1}{L^2} \hat{x}$
c. $\vec{E} = k\lambda \int_{-L}^{L} \frac{h dx}{(x^2+h^2)^{\frac{3}{2}}} \hat{y} + \frac{kQ_1}{L^2} \hat{x}$
d. $\vec{E} = k\lambda \int_{-L}^{L} \frac{dx}{(x^2+h^2)} \hat{y} + \frac{kQ_1}{L^2} \hat{x}$
e. $\vec{E} = k\lambda \int_{-L}^{L} \frac{x dx}{(x^2+h^2)^{\frac{3}{2}}} \hat{y} + \frac{kQ_1}{L^2} \hat{x}$

15) A second charge, Q_2, is placed at (L,h). What value should Q_2 take in order that the **total** electric field at (0, h) is zero

a. It is not possible to make the field at (0, h) vanish by placing a point charge at (L, h).
b. $Q_2 = Q_1$
c. $Q_2 = -Q_1$

The next three questions pertain to the situation described below.



A parallel plate capacitor with a large surface area A compared to the separation between the plates d has charge Q. After a certain time, a conducting slab with the same area A and a thickness of half the separation between the plates d/2 is inserted exactly in the middle of the two plates.

16) What is the relationship between the capacitance before, C, and after, C'?

a. C' = C/2
b. C' = C
c. C' = 2C

17) What is the relationship between the energy stored in the capacitor before, U, and after, U'?

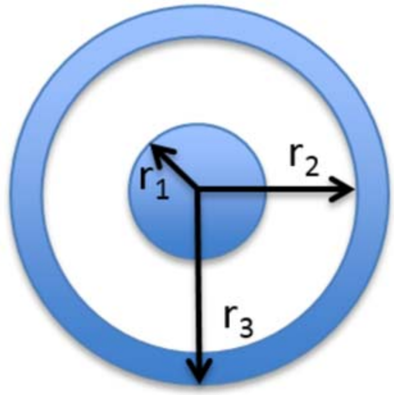
a. U' > U
b. U' = U
c. U' < U

18) Consider the "before" configuration shown above. In what direction can a charge be moved in the field created between the plates without doing any external work on the charge?

a. external work is always necessary
b. parallel to the y-axis
c. parallel to the x-axis

The next two questions pertain to the situation described below.

A solid conducting cylinder of radius r_1 and length L with charge Q is placed inside a hollow conducting cylinder of the same length L with inner radius r_2 and outer radius r_3 and charge –Q.



19) How does the capacitance change if r_2 is decreased slightly keeping L, r_1, and r_3 unchanged.

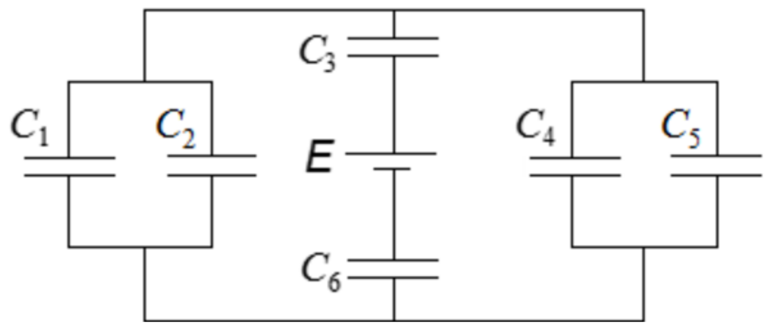
a. The capacitance remains the same.
b. The capacitance increases.
c. The capacitance decreases.

20) Suppose the cylinder is submerged in gasoline ($\varepsilon = 2.0$) so that there is gasoline between the plates. How does the capacitance change relative to the capacitance of the previous question?

a. $C_1 = 2\ C_0$
b. $C_1 = C_0/2$
c. $C_1 = C_0$

The next three questions pertain to the situation described below.

Six capacitors are connected to a battery as shown in the circuit diagram. The battery supplies E = 12 V.



$C_1 = 10\ \mu F$
$C_2 = 16\ \mu F$
$C_3 = 50\ \mu F$
$C_4 = 6\ \mu F$
$C_5 = 20\ \mu F$
$C_6 = 40\ \mu F$

21) What is the equivalent capacitance for the combination of the six capacitors?

a. $C_{123456} = 142\ \mu F$
b. $C_{123456} = 92.6\ \mu F$
c. $C_{123456} = 15.6\ \mu F$

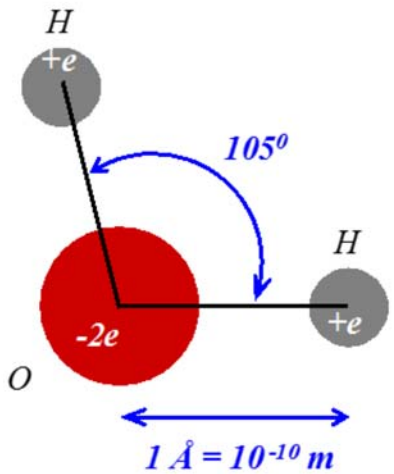
22) Which capacitors have the same charge

a. C_3 and C_6
b. C_1 and C_4
c. C_4 and C_5

23) What is the energy stored in capacitor C_3?

a. $U_3 = 3600\ \mu J$
b. $U_3 = 1120\ \mu J$
c. $U_3 = 350\ \mu J$

The next two questions pertain to the situation described below.



A water molecule may be crudely approximated as two positively charged hydrogen atoms and a negatively charged oxygen atom, as shown in the figure. Note the electron charge e = 1.6×10^{-19} C, and the separation between the two hydrogen atoms is 1.6×10^{-10}m.

24) What is the electric potential energy associated with this configuration of charges? (Let 0 corresponds to the three charges being infinitely far apart.)

a. -7.76×10^{-18} J
b. 1.45×10^{-18} J
c. -9.22×10^{-18} J

25) If the angle between the two hydrogen atoms is increased from 105 degrees to 180 degrees, while keeping the distance between the hydrogen and oxygen atoms fixed at 10^{-10} m, the electric potential energy of the system will

a. remain the same
b. increase
c. decrease

Physics 212 Formula Sheet

Electrostatics:

$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}^{\;2}}\hat{r}$$ $$\vec{E} \equiv \frac{\vec{F}}{q_0}$$ $$\Phi_E = \int \vec{E}\cdot d\vec{S}$$ $$\oint \vec{E}\cdot d\vec{S} = \frac{Q_{encl}}{\varepsilon_0}$$

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$ $$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\hat{r}$$ $$\vec{E} = \pm\frac{\sigma}{2\varepsilon_0}\hat{x}$$ $$V_B - V_A \equiv \frac{W_{AB}}{q_0} = -\int_A^B \vec{E}\cdot d\vec{l}$$

$$\vec{E} = -\vec{\nabla}V$$ $$U = q_0 V$$ $$U_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$ $$V(r) = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

$$\Delta V = \pm Ed$$

Capacitors and RC Circuits:

$$C \equiv \frac{Q}{V}$$ $$U = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\frac{Q^2}{C}$$ $$C = C_1 + C_2$$ $$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$C_0 = \frac{\varepsilon_0 A}{d}$$ $$C_0 = \frac{4\pi\varepsilon_0 ab}{(b-a)}$$ $$C_0 = \frac{2\pi\varepsilon_0 L}{\ln(b/a)}$$ $$C = \kappa C_0$$

$$Q(t) = Q(\infty)\left(1 - e^{-t/\tau}\right)$$ $$Q(t) = Q(0)e^{-t/\tau}$$ $$\tau = RC$$ $$u_E = \frac{1}{2}\varepsilon_0 E^2 \kappa$$

Simple Circuits:

$$R = \frac{V}{I}$$ $$R = \frac{\rho L}{A}$$ $$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$ $$R = R_1 + R_2$$

$$P = IV = I^2 R$$

Magnetostatics:

$$\vec{F} = q\vec{E} + q\vec{v}\times\vec{B}$$ $$d\vec{F} = Id\vec{l}\times\vec{B}$$ $$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l}\times\hat{r}}{r^2}$$ $$\oint \vec{B}\cdot d\vec{l} = \mu_0 I$$

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$ $$B_z = \frac{\mu_0 I R^2}{2(z^2 + R^2)^{3/2}}$$ $$B = \mu_0 n I$$ $$\vec{\mu} = NI\vec{A}$$

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

Induction and RL Circuits:

$$EMF = -\frac{d\Phi_B}{dt}$$ $$\Phi_B = \int \vec{B}\cdot d\vec{S}$$ $$L \equiv \frac{\Phi_B}{I}$$ $$V = L\frac{dI}{dt}$$

$$U = \frac{1}{2}LI^2$$ $$L = L_1 + L_2$$ $$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$$ $$I(t) = I(0)e^{-t/\tau}$$

$$I(t) = I(\infty)\left(1 - e^{-t/\tau}\right)$$ $$\tau = \frac{L}{R}$$ $$u_B = \frac{1}{2}\frac{B^2}{\mu_0}$$

LC, LCR, and AC Circuits:

$$\omega_0 = \frac{1}{\sqrt{LC}} \qquad X_C \equiv \frac{1}{\omega C} \qquad X_L \equiv \omega L \qquad \tan\phi = \frac{X_L - X_C}{R}$$

$$Z \equiv \sqrt{R^2 + (X_L - X_C)^2} \qquad \varepsilon_{\max} = I_{\max} Z \qquad \varepsilon_{rms} = \frac{1}{\sqrt{2}}\varepsilon_{\max} \qquad V_2 = \frac{N_2}{N_1} V_1$$

$$\langle P \rangle = \varepsilon_{rms} I_{rms} \cos\phi = \frac{1}{2}\varepsilon_{\max} I_{\max}\cos\phi = I_{rms}^2 R \qquad Q = \frac{\omega_0 L}{R} \approx \frac{\omega_0}{FWHM} \qquad I_1 V_1 = I_2 V_2$$

EM Waves, Polarization, Reflection and Refraction:

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I + \mu_0 I_D \qquad I_D = \varepsilon_0 \frac{d\phi_E}{dt} \qquad E = cB \qquad I = c\langle u \rangle = \frac{\langle E^2 \rangle}{Z_0} = \frac{1}{2}\frac{E_{\max}^2}{Z_0} = \frac{\langle P \rangle}{area}$$

$$\vec{S} \equiv \frac{\vec{E}\times\vec{B}}{\mu_0} \qquad \vec{B} = \hat{s}\times\frac{\vec{E}}{c} \qquad u = \varepsilon_0 E^2 \qquad \frac{I}{c} = \frac{force}{area} \qquad E_{rms} = \frac{1}{\sqrt{2}} E_{\max}$$

$$\omega = 2\pi \mathrm{f} \qquad \mathrm{v} = \lambda f = \frac{\omega}{k} \qquad I_2 = I_1 \cos^2(\theta_1 - \theta_2) \qquad \mathrm{v} = c/n \qquad \frac{\lambda_1}{\lambda_2} = \frac{\mathrm{v}_1}{\mathrm{v}_2} = \frac{n_2}{n_1}$$

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad \sin\theta_{\mathrm{c}} = \frac{n_2}{n_1} \qquad f' = f\sqrt{\frac{1 \pm \mathrm{v/c}}{1 \mp \mathrm{v/c}}} \qquad f' \approx f\left(1 \pm \mathrm{v/c}\right)$$

Mirrors and lenses:

$$f = \frac{R}{2} \qquad \frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \qquad \frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad m = -\frac{s'}{s} \qquad power = \frac{1}{f}\,[Diopters]$$

Energy:

$$K = \frac{1}{2} m \mathrm{v}^2 \qquad E = K + U = \text{const.}$$

Centripetal Force:

$$F_c = m\frac{\mathrm{v}^2}{r}$$

Important Constants:

$$k \equiv \frac{1}{4\pi\varepsilon_\circ} = 9\times 10^9 \ \frac{\mathrm{Nm}^2}{\mathrm{C}^2} \qquad \varepsilon_0 = 8.85\times 10^{-12}\ \frac{C^2}{Nm^2} \qquad \frac{\mu_0}{4\pi} \equiv 1\times 10^{-7}\ \frac{\mathrm{N}}{\mathrm{A}^2} = 1\times 10^{-7}\ T_m/A$$

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3\times 10^8\,\mathrm{m/s} \qquad e = 1.60\times 10^{-19}\ \mathrm{C} \qquad Z_0 = \mu_0 c = 377\,\Omega$$

SI Prefixes Power	Prefix	Symbol
10^6	mega	M
10^3	kilo	k
10^0	—	—
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Geometry

Circle

area $= \pi R^2$

circumf. $= 2\pi R$

Sphere

area $= 4\pi R^2$

volume $= \frac{4}{3}\pi R^3$

$$\vec{\nabla} V = \hat{x}\frac{\partial V}{\partial x} + \hat{y}\frac{\partial V}{\partial y} + \hat{z}\frac{\partial V}{\partial z}$$