Physics 7B Midterm 1

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17 Temperature, Thermal Expansion, and Ideal Gas Law

17.1

atomic mass (molecular mass) [u]: relative masses of atoms/molecules, numerically same as molar mass

Conversions

$1u = 1.6605 \times 10^{-27}$ kg

$C = \frac{5}{9}(F - 32)$

$F = \frac{9}{5}(C) + 32$

$K = C + 273.15$

17.2

Temperature [C°/F°/K]: how hot or cold something is

Freezing	Boiling
0° C	100° C
32° F	212° F

17.3

Zeroth Law of Thermodynamics: If two systems are in thermal equilibrium w/ a third system, they are in thermal equibrium w/ each other

17.4

Linear Expansion:

$$\Delta l = \alpha l_0 \Delta T \qquad l = l_0(1 + \alpha \Delta T)$$

α: coefficient of linear expansion $\left[\frac{1}{C°}\right]$; $T - T_0$

NOTE: ring expands linearly by diameter

Volume Expansion:

$$\Delta V = \beta V_0 \Delta T$$

coefficient of volume expansion $\left[\frac{1}{C°}\right]$

for isotropic: $\Delta V \approx (3\alpha) V_0 \Delta T$

$$V = l_0(1+\alpha\Delta T) W_0(1+\alpha\Delta T) H_0(1+\alpha\Delta T)$$

17.6

Boyle's Law

$V \propto \frac{1}{P}$

Charles's Law

$V \propto T$

Gay-Lussac's Law

$P \propto T$

17.7

mole [n]: amount of substance containing same atoms in 12g of C

$$n \text{ (moles)} = \frac{\text{mass (g)}}{\text{molecular mass } \left(\frac{g}{mol}\right)}$$

Ideal Gas Law:

$$PV = nRT$$

T: temperature [K]; n: moles; R: universal gas constant: $8.314 \frac{J}{mol \cdot K} = 1.99 \frac{cal}{mol \cdot K}$

PV

Standard Temperature Pressure (STP): T = 273 K P = 1 atm = 101.3 kPa

17.9

Avagadro's number: number of molecules in one mole

$N_A = 6.022 \times 10^{23}$

$$PV = nN_AkT = NkT = \frac{N}{N_A}RT$$

$N = nN_A$

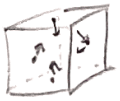
Boltzmann Constant $\left(\frac{R}{N_A}\right) = 1.38 \times 10^{-23} \frac{J}{K}$

18 Kinetic Theory of Gases

18.1

Ideal Gas Law assumptions:

1. Large number of molecules N, mass m, moving in random directions different speeds
2. Molecules on average far apart from each other
3. Obey classical mechanics, interact when they collide
4. Collisions w/ wall or molecules elastic.



Average translational kinetic energy is proportional to temperature

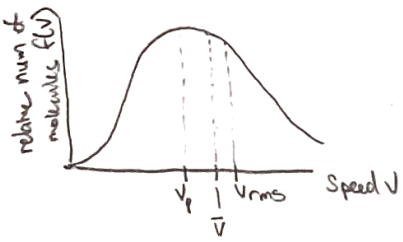
$$\bar{K} = \frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$$

root-mean-square speed: how fast molecules move on avg

$$v_{rms} = \sqrt{\bar{v}^2} = \sqrt{\frac{3kT}{m}}$$

18.2

Maxwell Distribution of speeds: probable distribution of speeds in gas w/ N molecules



$$f(v) = 4\pi N\left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} v^2 e^{-\frac{1}{2}\frac{mv^2}{kT}}$$

$$\int_0^\infty f(v)\,dv = N$$

most probable $v_p = \sqrt{2\frac{kT}{m}} \approx 1.41\sqrt{\frac{kT}{m}}$

avg speed $\bar{v} = \sqrt{\frac{8}{\pi}\frac{kT}{m}} \approx 1.60\sqrt{\frac{kT}{m}}$

rms speed $v_{rms} = \sqrt{3\frac{kT}{m}} \approx 1.73\sqrt{\frac{kT}{m}}$

Expected Value of F

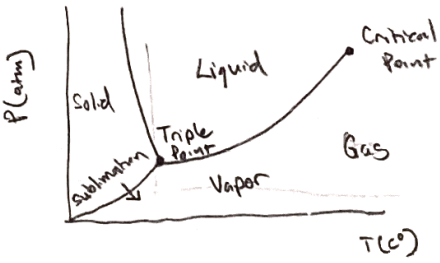
$$\langle F(x)\rangle = \int F(x)p(x)\,dx$$

18.3

Liquid crystals between liquid and solid

Sublimation: Solid → vapor

Phase diagram:



18.4

Evaporation: liquid → gas

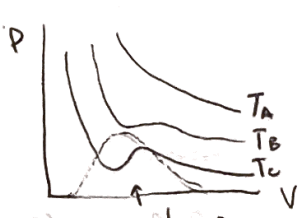
Condensation: gas → liquid

saturated vapor pressure: equilibrium between liquid, vapor

Boiling when saturated vapor pressure = external pressure

relative humidity: $\frac{\text{partial pressure } H_2O}{\text{saturated vapor pressure } H_2O} \times 100$

Van der Waals



18.5

Van der Waals takes into account 1) finite size of molecules, 2) range of forces between molecules > size molecules

$$P = \frac{RT}{\left(\frac{V}{n}\right) - b} - \frac{a}{\left(\frac{V}{n}\right)^2}$$

$$\left(P + \frac{a}{\left(\frac{V}{n}\right)^2}\right)\left(\frac{V}{n} - b\right) = RT$$

a, b different for different gases

19 Heat and First Law of Thermodynamics

Conversions

1000 cal = 1 kcal = 4184 J

1 L·atm = 101.33 J

$F = PA$

19.1

Unit of heat: calorie (cal), kilocalorie (kcal): amount of heat necessary to raise 1 g of water by 1°C

heat: energy transferred from one object to another bc difference in temperature

19.2

Internal Energy: sum total of all energy of all molecules in an object

Temperature	vs.	Internal Energy	vs.	Heat
avg kinetic energy of individual molecules		total energy of all the molecules		transfer of energy from one object to another

Internal Energy (E_{int}): $E_{int} = \frac{3}{2} nRT$ for monatomic gas

19.3

Heat Q to change temp of material: $Q = mc\Delta T$

specific heat $\left[\frac{J}{kg \cdot C}\right]$: specific to material

19.4

Systems:

Open System

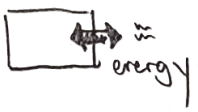
mass can be transferred

energy can be transferred

Closed System

mass cannot be transferred

energy can be transferred



Closed (Isolated)

mass cannot be transferred

energy cannot be transferred

In isolated environments: heat lost = heat gained

$Q_1 = Q_2$

19.5

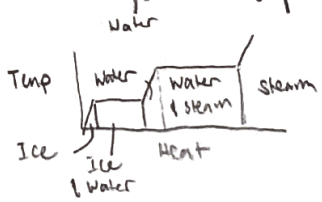
Energy is involved in change of phase

Heat of fusion (L_F): heat to change 1 kg substance solid → liquid

Heat of vaporization (L_V): heat to change 1 kg substance liquid → vapor

$\left\{\left[\frac{kJ}{kg}\right]\right.$

$Q = mL$ ← Latent Heat



energy is needed to break attractive forces

19.6

First Law of Thermodynamics: $\boxed{\Delta E_{int} = Q - W}$

net heat added to system — net work done by system

Heat added: +
Heat lost: −
Work on System: −
Work by System: +

Thermodynamics; degrees of freedom

$$\boxed{\Delta E_{int} = \frac{d}{2} nR\Delta T}$$

$$\boxed{W = \int_{V_1}^{V_2} P\,dV}$$

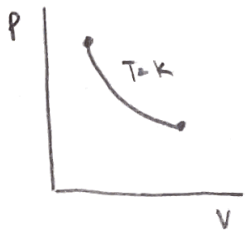
$$\boxed{\Delta E_{int} = Q - W}$$

19.7

1) **Isothermic** $(\Delta T = 0)$

$\Delta E_{int} = 0$, so $Q = W$

$W = nRT \ln\left(\frac{V_2}{V_1}\right)$

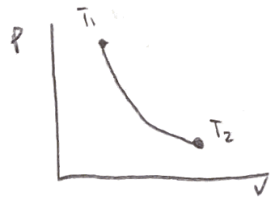


2) **Adiabatic** $(Q = 0)$

$\Delta E_{int} = -W = \frac{d}{2} nR\Delta T$

$PV^{\gamma} \Rightarrow \frac{P_1}{P_2} = \left[\frac{V_2}{V_1}\right]^{\gamma} = \left[\frac{T_1}{T_2}\right]^{\frac{\gamma}{\gamma-1}}$

Monatomic: $\gamma = 5/3$ $d = 3$
Diatomic: $\gamma = 1.4$ $d = 5$
Triatomic: $\gamma = 1.31$ $d = 7$

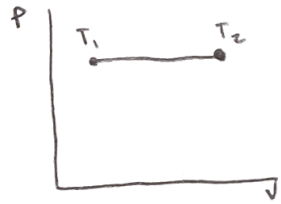


3) **Isobaric** $(\Delta P = 0)$

if ideal: $W = nRT_2\left(1 - \frac{V_1}{V_2}\right)$

else: $W = P\Delta V$

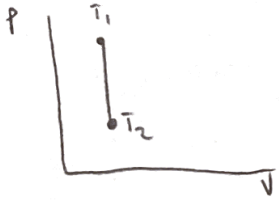
$Q = \Delta E_{int} + P\Delta V$



4) **Isovolumetric** $(\Delta V = 0)$

$W = 0$

$\Delta E_{int} = Q = \frac{d}{2} nR\Delta T$



x] For problems, set up table

	a	b	c	ab	bc	ca
P						
V						
T						
ΔE_{int}						
Q						
W						

19.8

Molar Specific Heats (C_v, C_p): heat required to raise 1 mol of gas by 1 C° const volume, temp

Constant Volume

$\boxed{Q = n C_v \Delta T}$

$C_v = M c_v$ ← specific heat @ const volume; molecular mass $\left[\frac{g}{mol}\right]$

$\Delta E_{int} = Q$

$C_v = \frac{3}{2} R$

Constant Pressure

$\boxed{Q = n C_p \Delta T}$

$C_p = M c_p$

- More heat is required, need work

$Q_p - Q_v = P\Delta V$

$C_p - C_v = R$

19.13

•Heat transfer via:

1) Conduction: hot to cold via molecular collisions

$$\frac{dQ}{dt} = -kA\frac{dT}{dx}$$

↑ thermal conductivity constant (specific to metal)

2) Convection: heat flows by mass movement of molecules

3) Radiation: heat by electromagnetic waves

Stephan-Boltzmann eq: $\frac{\Delta Q}{\Delta t} = e\sigma A T^4$

emissivity: [0,1] characteristic of surface

A ← area of emitting object

Stephan-Boltzmann constant: $\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 \cdot K^4}$

Sun radiation heat: $\frac{\Delta Q}{\Delta t} = \left(1000 \frac{W}{m^2}\right) e A \cos\theta$

20 Second Law of Thermodynamics

20.2

Heat Engines produce Work from thermal energy

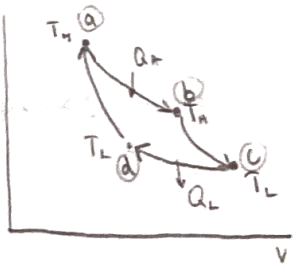
$$Q_H = W + Q_L \qquad \Delta E_{int} = 0$$

Efficiency (e): ratio of Work done to heat input

$$e = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

20.3

Carnot's Engine is an idealized reversible cycle



ab 1) expanded isothermally, Q_H added

bc 2) expanded adiabatically, temperature reduced to T_L

cd 3) compressed isothermally, Q_L removed

da 4) compressed adiabatically, temperature raised to T_H

$$\frac{Q_L}{Q_H} = \frac{T_L}{T_H} \qquad e_{ideal} = 1 - \frac{T_L}{T_H}$$ ← [K]

20.4

Coefficient of Performance (COP): heat removed for work done

refrigerator

$$COP = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L}$$

$$COP_{ideal} = \frac{T_L}{T_H - T_L}$$

20.5

Entropy [S] is a state variable, measure of order or disorder

20.6

$$\Delta S = \Delta S_H + \Delta S_L = -\frac{Q}{T_{HM}} + \frac{Q}{T_{LM}}$$ For hot → cold, $\Delta S > 0$

$$\Delta S = \frac{Q}{T} = \int_{T_1}^{T_2} \frac{mc\,dT}{T} = mc \ln\left(\frac{T_2}{T_1}\right)$$

Entropy of isolated system never decreases.

$$\Delta S = \Delta S_{syst} + \Delta S_{env} > 0$$

20.7

Second Law of Thermodynamics: Natural Processes tend to move toward a state of greater disorder

20.8

Energy eventually becomes degraded and unavailable to do useful work

Tips

* Remember to change T to Kelvins

Units / Conversions

Force	Newton [N]	$\frac{m \cdot kg}{s^2}$	
Pressure	Pascal [Pa]	$\frac{kg}{m \cdot s^2}$	
Energy	Joule [J]	$\frac{m^2 \cdot kg}{s^2}$	
Energy	calone [cal]	$\frac{m^2 \cdot kg}{s^2}$	
Power	Watt [W]	$\frac{J}{s} = \frac{kg \cdot m^2}{s^3}$	
Gas constant	[R]		

$F = PA$ (P: Pressure) $\quad F = \frac{p}{t}$ (p: momentum, $p = mv$)

101,325 Pa = 1 atm = 760 mmHg = 14.7 psi

1000 J = 1 kJ, 101.33 J = 1 L·atm

1000 cal = 1 kcal, 1 cal = 4.184 J

745.7 W = 1 hp, power → $P = \frac{W}{\Delta t}$

8.314 $\frac{J}{mol \cdot K}$ = 1.99 $\frac{cal}{mol \cdot K}$

$KE = \frac{1}{2} mv^2$ $\quad \Delta K + \Delta U + \Delta E_{mt} = Q - W$

21 Electric Charge and Electric Field

21.1 Unlike charges attract, like charges repel

Law of conservation of electric charge: net amount of electric charge produced is 0

21.2 Atom has positively charged nucleus w/ protons and neutrons, electrons surrounding
Becomes an ion if loses or gains an electron

21.3 Conductors - electrons are bound loosely, charge transfers easily
Insulators - electrons bound tightly to nucleus, charge does not transfer easily
Semiconductor - intermediate category, fewer free electrons

21.4 Charging by conduction - using charged object to make neutral object charged by contact
Induced charge - caused neutral object to be charged without contact

21.5 Coulomb's Law:

$$F = k\frac{Q_1 Q_2}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$$

$k = \frac{1}{4\pi\varepsilon_0}$ used for Point charges

F: Magnitude of Electric Force
$k = 8.99\times10^9 \frac{N\cdot m^2}{C^2}$
ε_0: permitivity of free space, $\varepsilon_0 = 8.85\times10^{-12}\frac{C^2}{N\cdot m^2}$

Charge (Q) measured in Coulomb [C]

elemtary charge: $e = 1.602\times10^{-19}\,C$

Principle of superposition - net force on object w/ multiple charges is vector sum of forces due to each of others

21.6 Each object radiates Electric field, use small positive test charge to measure field

Electric Field →

$$\vec{E} = \frac{\vec{F}}{q} \qquad E = k\frac{Q}{r^2} \qquad \vec{F} = q\vec{E}$$

$\vec{F}$: magnitude of test charge
q: Force at q

Positive charge: E field points away, Negative: points toward

If multiple charges: Superposition Principle: $\vec{E} = \vec{E}_1 + \vec{E}_2 + \dots$

draw diagram, find mag w/ Coulombs, add vector forces

21.7 Continous charge Distribution problems

1) Choose Coordinate System (Cartesian, Polar, Spherical, Cylindrical)

$\frac{Q}{x} = \lambda$ $\frac{Q}{A} = \sigma$ $\frac{Q}{V} = \rho$

2) find dq λ: $dq = \lambda\,dx$, λ: Linear charge density
$dq = \sigma\,dA$, σ: surface charge density
$dq = \rho\,dV$, ρ: volume charge density

$dA = dx\,dy = r\,dr\,d\theta$
$dV = dx\,dy\,dz = r^2\sin\theta\,d\theta\,d\phi\,dr = r\,dr\,dy\,dz$

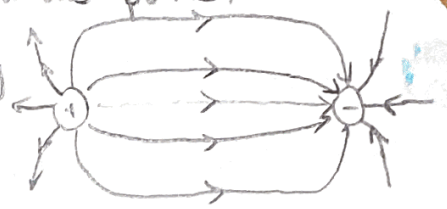
3) find dE

$$dE = \frac{1}{4\pi\varepsilon_0}\frac{dQ}{r^2} \qquad dE = \frac{1}{4\pi\varepsilon_0}\frac{dQ}{r^2}\hat{r}$$

4) Find E

$$\vec{E} = \int d\vec{E}$$

21.8 Electric field lines indicate the direction of electric field at various points.



the closer the lines, the stronger, lines start on pos end on neg

21.9 Electric Fields and Conductors:
- Electric field inside conductors is 0
- Electric field is always perpendicular to surface outside conductor

21.10 Magnitude of electron acceleration $a = \frac{F}{m} = \frac{qE}{m}$

21.11 Electric Dipole - two equal charges w/ opposite signs separated by distance l

Dipole moment: $\vec{p} = Ql$

Torque: $\vec{\tau} = \vec{p} \times \vec{E} = pE\sin\theta$

Work: $W = \int_{\theta_1}^{\theta_2} \tau \, d\theta = pE(\cos\theta_2 - \cos\theta_1)$

22 Gauss's Law

22.1 Electric flux: electric field passing through area

For uniform electric field $\vec{E}$ through A

Flux → $\Phi_E = EA\cos\theta$

For Not uniform $\Phi_E = \oint \vec{E} \cdot d\vec{A}$

22.2 flux entering enclosed volume is negative, leaving is positive, nonzero when enclosed charge

Gauss's Law: $\oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$ ← net charge enclosed in surface

Solving w/ Gauss:
1) Find surface S that respects symmetry
2) $\int E \cdot dA = |E| \cdot$ Surface Area of S
3) $Q_{encl} \Rightarrow \int dq = \lambda dx, \sigma dA, \rho dV$

22.3 If conductor w/ charge Q and inside cavity has charge +q
Must be -q charge on surface of cavity and outer surface with Q+q

23 Electric Potential

23.1 Electric Potential Energy (U) - conservative force for electrostatic

$\Delta U = -W = -qEd$ [Uniform $\vec{E}$]

Electric Potential (V) - electric potential energy per unit charge

$V_a = \frac{U_a}{q}$ $\Delta V = \frac{U_b - U_a}{q} = \frac{-W_b}{q}$

Voltage(V) - Potential Difference $1V = 1\ J/C$ measures how much work a given charge can do

$\Delta U = qV_{ba}$

$\Delta V = -\int \vec{E} \cdot d\vec{l}$ since E is force per unit charge $E = \frac{F}{q}$

23.3 Electric Potential at distance r away

$$\Delta V = -\int_{r_b}^{r_a} \vec{E} \cdot d\vec{l} = -\frac{Q}{4\pi\varepsilon_0} \int_{r_b}^{r_a} \frac{1}{r^2} dr = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r_b} - \frac{Q}{r_a}\right)$$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r} \quad \left[\text{single pt charge, } V=0 \text{ at } r=\infty\right]$$

23.4 with continuous distribution

$$V = \frac{1}{4\pi\varepsilon_0}\int \frac{dq}{r} \qquad V = -\int E\,dr$$

can add together voltages since scalar

23.5 Equipotential lines with same potential, perpendicular to electric field

23.6 Electric Dipole Potential

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q l\cos\theta}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2} \quad [\text{dipole, } r \gg l]$$

23.7 $E_l = -\frac{dV}{dl}$ $\quad E_x = -\frac{\partial V}{\partial x}, E_y = -\frac{\partial V}{\partial y}, E_z = -\frac{\partial V}{\partial z}$

23.8 Charges moved from $V=0$ $r=\infty$

$$U = Q_2 V = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r_{12}} \qquad U = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q_1 Q_2}{r_{12}} + \frac{Q_1 Q_3}{r_{13}} + \frac{Q_2 Q_3}{r_{23}}\right)$$

electron Volt (eV) $\quad 1\,eV = 1.6\times10^{-19}\,J$

24 Capacitance, Dielectrics, Electric Energy Storage

24.1 Capacitors - store electric charge by using two conducting objects

capacitor [⊣⊢] battery [⏤⏤]

amount of charge acquired by plate $\quad Q = CV$ ← capacitance [F] Farad $\frac{C}{V}$

24.2 Capacitance $\quad C = \varepsilon_0 \frac{A}{d}$ ← area of plates, ← distance between plates

24.3 Parallel: $Q = C_{eq}V \quad C_{eq} = C_1 + C_2$

Series: $Q = C_{eq}V \quad C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$

24.4 Harder to charge capacitor the more energy it has

Work to charge $W = \int_0^Q V\,dq = \frac{1}{C}\int_0^Q q\,dq = \frac{1}{2}\frac{Q^2}{C}$

Energy stored $U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}QV = \frac{1}{2}CV^2$

Energy Density (u) $\frac{\text{energy}}{\text{volume}}$: $u = \frac{1}{2}\varepsilon_0 E^2$ $\quad E = \frac{Q}{\varepsilon_0 A}$

24.5 Dielectric: piece of insulating sheet of material in between plates

$C = K C_0$ ← capacitance if space is vacuum

↑ Dielectric constant

$C = K\varepsilon_0 \frac{A}{d}$ $\quad \varepsilon = K\varepsilon_0$ ← permitivity of dielectric

25 Electric Currents and Resistance

25.2 Current only flows with complete circuit

$I = \frac{dQ}{dt}$ Current [I] measured in Amperes [A] $1A = 1\frac{C}{s}$

25.3 Ohm's Law: $V = IR$

↑ Resistance of a wire [Ω] Ohms $1\Omega = 1\frac{V}{A}$

25.9 Resistivity

$R = \rho\frac{l}{A}$ $\quad dR = \rho\frac{dl}{A}$ ← wire length l, ↑ cross sectional area

↑ resistivity [Ω·m]

$\sigma = \frac{1}{\rho}$ ↑ conductivity $\left[\frac{1}{\Omega\cdot m}\right]$

resistivity can vary based on temperature

$\rho_T = \rho_0\left[1 + \alpha[T - T_0]\right]$

↑ resistivity Temp T ↑ resistivity at temp T_0

25.5 $P = IV = I^2R = \frac{V^2}{R}$ ← applies to resistors

Power [W] Watt $1W = 1\frac{J}{s}$

Can be measured in kilo watt-hour (kWh) $1kWh = 3.6\times10^6 J$

25.7 $V = V_0\sin(\omega t)$ $\quad +V_0$ / $-V$ peak voltage

$I = I_0\sin(\omega t)$ $\quad I_0 = V_0/R$ peak current

$P = I^2R = I_0^2R\sin^2\omega t$

$I_{rms} = \sqrt{\overline{I^2}} = \frac{I_0}{\sqrt{2}} = 0.707 I_0$ $\quad V_{rms} = \sqrt{\overline{V^2}} = \frac{V_0}{\sqrt{2}} = 0.707\ V_0$

$\overline{P} = I_{rms} V_{rms} = \frac{1}{2} I_0^2 R = I_{rms}^2 R = \frac{1}{2}\frac{V_0^2}{R} = \frac{V_{rms}^2}{R}$

26.8

$\vec{J}$ current per unit cross-sectional area

$\Delta Q = (\#\ \text{charges}, N) \times (\text{charges per particle})$

$= (nV)(+e) = -(nAv_d \Delta t)e$

Current

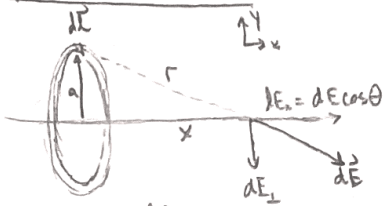
$I = \frac{\Delta Q}{\Delta t} = -nevA v_d$

$V = \frac{I}{A}$ $\quad \vec{J} = -ne\vec{v}_d$

Constant / Example Reference

Coulomb's

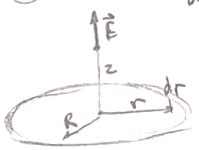
$E = \frac{1}{4\pi\varepsilon_0}\frac{Qx}{(x^2+a^2)^{3/2}}$



$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{(x^2+a^2)^{1/2}}$

Coulomb's

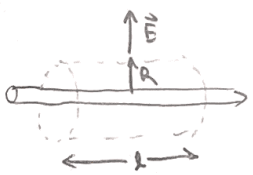
$E = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{z}{(z^2+R^2)^{\frac{1}{2}}}\right]$



$V = \frac{Q}{2\pi\varepsilon_0 R^2}\left[(z^2+R^2)^{1/2} - z\right]$

Coulomb's
Gauss

$E = \frac{1}{2\pi\varepsilon_0}\frac{\lambda}{R}$



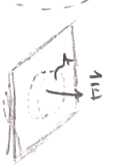
Gauss

$r > r_0: \ E = \frac{Q}{4\pi\varepsilon_0 r^2}$

$r < r_0: \ E = \frac{Qr}{4\pi\varepsilon_0 r_0^3}$

$r > r_0: \ V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$

Gauss



$E = \frac{\sigma}{2\varepsilon_0}$

Constants

$k = 8.99 \times 10^9 \ \frac{N \cdot m^2}{C^2}$

$\varepsilon_0 = 8.85 \times 10^{-12} \ \frac{C^2}{N \cdot m^2}$

$e = 1.602 \times 10^{-19}\ C$

Surface Area of Sphere: $4\pi r^2$