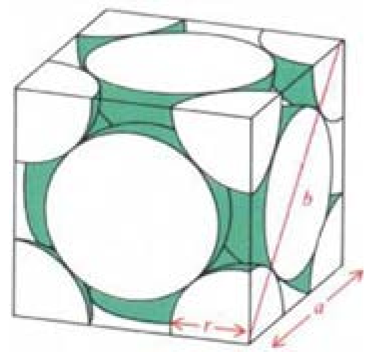
PHYS 226 – Spring 2017
Final exam



Name: ________________________________
Pledged: ________________________________
Please write your answer on the exam sheet.

Useful stuff that you may (or may not) need

Unit conversions

Length and Volume

$1\ \text{m} = 100\ \text{cm} = 39.370\ \text{in} = 3.2808\ \text{ft}$
$1\ \text{mi} = 1.6093\ \text{km} = 5280\ \text{ft}$
$1\ \text{in} = 2.54\ \text{cm}$
$1\ \text{nm} = 10^{-9}\ \text{m} = 1\ \text{Å}$
$1\ \text{m}^3 = 1000\ \text{L} = 264.17\ \text{gal (US)}$
$1\ \text{mL} = 10^{-3}\ \text{L} = 10^{-6}\ \text{m}^3 = 1\ \text{cm}^3$

Speed and Time

$1\ \text{m} \cdot \text{s}^{-1} = 2.2369\ \text{mi} \cdot \text{h}^{-1}$
$1\ \text{h} = 3600\ \text{s}$

Force and Pressure

$1\ \text{N} = 10^6\ \text{dyne} = 0.22481\ \text{lb}$
$1\ \text{ton (US)} = 2000\ \text{lb}$
$1\ \text{Pa} = 1\ \text{N} \cdot \text{m}^{-2}$
$1\ \text{atm} = 760\ \text{mmHg} = 1.01325 \times 10^5\ \text{Pa}$
$= 14.696\ \text{psi}$

Energy and Power

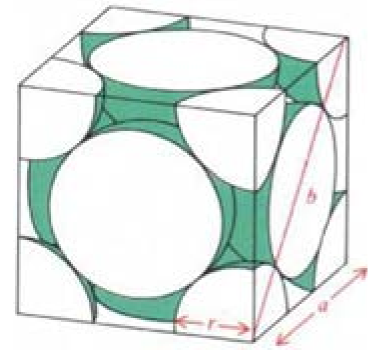
$1\ \text{J} = 1\ \text{N} \cdot \text{m} = 1\ \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2} = 0.23901\ \text{cal}$
$1\ \text{eV} = 1.60217 \times 10^{-19}\ \text{J}$
$1\ \text{hp (US)} = 0.74570\ \text{kW}$

Physical constants

Gravitational field at sea level $g = 9.80\ \text{m} \cdot \text{s}^{-2} = 9.80\ \text{N} \cdot \text{kg}^{-1}$
Gravitational constant $G = 6.67384 \times 10^{-11}\ \text{N} \cdot \text{m}^2 \cdot \text{kg}^{-2}$
Avogadro constant $N_\text{A} = 6.0221 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant $R = 8.3145\ \text{J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1} = 0.082057\ \text{L} \cdot \text{atm} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$
Boltzmann constant $k_\text{B} = 1.38065 \times 10^{-23}\ \text{J} \cdot \text{K}^{-1}$
Mass of Earth $M_E = 5.972 \times 10^{24}\ \text{kg}$
Mean radius of Earth $R_E = 6.371 \times 10^6\ \text{m}$
Density of water (3.98° C) $\rho_w = 1.000 \times 10^3\ \text{kg} \cdot \text{m}^3$
Elementary charge $e = 1.6022 \times 10^{-19}\ \text{C}$
Electron mass $m_e = 9.1094 \times 10^{-31}\ \text{kg}$
Proton mass $m_P = 1.6726 \times 10^{-27}\ \text{kg}$
Coulomb constant $k = 1/4\pi\varepsilon_0 = 8.98755 \times 10^9\ \text{N} \cdot \text{m}^2 \cdot \text{C}^{-2}$
Permittivity of free space $\varepsilon_0 = 8.8542 \times 10^{-12}\ \text{C}^2 \cdot \text{N}^{-1} \cdot \text{m}^{-2}$
Permeability of free space $\mu_0 = 1.2566 \times 10^{-6}\ \text{N} \cdot \text{A}^{-2}$
Refractive index of freshwater $= 1.33$
Refractive index of seawater $= 1.35$

Q.1 Shipping container A shipping container is floating in the ocean with 23.0% of its height submerged in the seawater (density $1030\ \mathrm{kg/m^3}$). The container is 40.0 ft long by 8.00 ft wide by 8.50 ft high and has a mass of 3802 kg when it's empty. The police want you to estimate the mass of the container's contents.

Q.2 FCC volume *Calculate* the actual volume occupied by the spheres in the face-centered cubic structure shown in the figure as a percentage of the total volume.



Q.3 Strain *Calculate* the strain in a steel wire under a tensile stress of $1.0 \times 10^7\ \mathrm{N/m^2}$. What is percentage contraction in diameter of the wire under such a load? For the steel in the wire: Young's modulus is $Y = 210\ \times 10^9\ \mathrm{N/m^2}$, the modulus of rigidity is $G = 84\ \times 10^9\ \mathrm{N/m^2}$, the bulk modulus is $K = 210\ \times 10^9\ \mathrm{N/m^2}$ and Poisson's ratio is $\nu = 0.29$.

Q.4 Fermi energy The Fermi energy for lithium is $4.72\ \mathrm{eV}$ at $T = 0\ \mathrm{K}$. **(a)** *Calculate* the number of conduction electrons per unit volume in lithium. **(b)** How many electrons per atom is this? The density of lithium is $535\ \mathrm{kg/m^3}$.

Q.5 Lizzie's show-that problem From pages 156 and 157 of chapter 6 of Turton, Lizzie knows that

$$N_d l_n = N_a l_p \tag{6.5}$$

and

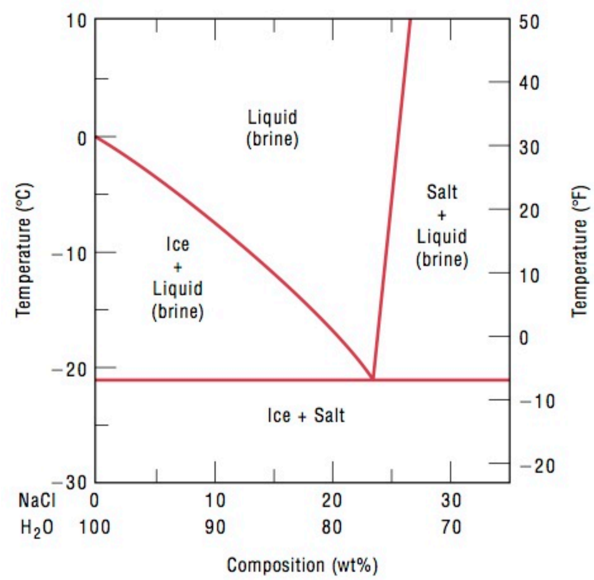
$$\phi = \frac{e}{2\varepsilon\varepsilon_0}\left(N_d l_n^2 + N_a l_p^2\right) \tag{6.6}$$

Using equations (6.5) and (6.6), *show that* the widths of the depletion layer on the p- and n-sides of a p-n junction are given by equations (6.7) and (6.8), respectively.

$$l_p = \sqrt{\frac{\phi 2\varepsilon\varepsilon_0}{eN_a}\frac{N_d}{N_a + N_d}} \tag{6.7}$$

$$l_n = \sqrt{\frac{\phi 2\varepsilon\varepsilon_0}{eN_d}\frac{N_a}{N_a + N_d}} \tag{6.8}$$

Q.6 Salt on the driveway The constitutional phase diagram for salt and water is shown on the right.



(a) Using this diagram, *briefly explain* how spreading salt on ice that's below 0°C can cause the ice to melt.

(b) What wt% of salt is necessary to completely melt ice at −10°C ?

(c) What wt% of salt is necessary to have a 50% ice – 50% liquid brine at −10°C ?

(d) What is the composition of the resulting brine?

(e) According to the solute blocking model, what process is slowed down by the presence of salt in the brine?

Q.7 Magnetization Consider a solid consisting of N atoms each with magnetic moment $\mu = 1\mu_B$ where $\mu_B = e\hbar/2m_e$. In the presence of an external magnetic field of strength B_0, each atom has two possible energy states — parallel to the field (with energy $E = -\mu_B B_0$), and anti-parallel to the field (with energy $E = \mu_B B_0$). The probability of finding one atom with an energy E is given by $p(E) = A\exp(-E/k_B T)$.

(a) Determine A.

Hint: The two probabilities must add up to one.

(b) Show that the average magnetic moment is $\langle\mu\rangle = \mu_B \tanh\frac{\mu_B B_0}{k_B T}$, so that the magnetization M is given by $M = N\,\langle\mu\rangle = N\mu_B \tanh\frac{\mu_B B_0}{k_B T}$.

Hint: $\tanh x = \frac{e^x - e^{-x}}{e^x + e^{-x}}$

(c) What does this equation give for the magnetization at low fields and at very large fields?

(d) Compare your answer to part (c) for low fields with Curie's law $M = CB_0/T$.

(e) Is this solid diamagnetic, paramagnetic, or ferromagnetic?

Q.8 Superconductor For a superconducting material at a temperature T below the critical temperature T_c, the critical field $H_c(T)$, depends on temperature according to the relationship

$$H_c(T) = H_c(0)\left(1 - \frac{T^2}{T_c^2}\right)$$

where $H_c(0)$ is the critical field at 0 K.

(a) Using the data in Table 18.7, calculate the critical magnetic fields for lead at 1.5 K and 3.5 K.

Table 18.7 Critical Temperatures and Magnetic Fluxes for Selected Superconducting Materials

Material	*Critical Temperature T_C (K)*	*Critical Magnetic Flux Density B_C (tesla)*[a]
	Elements[b]	
Tungsten	0.02	0.0001
Titanium	0.40	0.0056
Aluminum	1.18	0.0105
Tin	3.72	0.0305
Mercury (α)	4.15	0.0411
Lead	7.19	0.0803
	Compounds and Alloys[b]	
Nb-Ti alloy	10.2	12
Nb-Zr alloy	10.8	11
$PbMo_6S_8$	14.0	45
V_3Ga	16.5	22
Nb_3Sn	18.3	22
Nb_3Al	18.9	32
Nb_3Ge	23.0	30
	Ceramic Compounds	
$YBa_2Cu_3O_7$	92	—
$Bi_2Sr_2Ca_2Cu_3O_{10}$	110	—
$Tl_2Ba_2Ca_2Cu_3O_{10}$	125	—
$HgBa_2Ca_2Cu_2O_8$	153	—

(b) To what temperature must lead be cooled in a magnetic field of 20,000 A/m for it to be superconductive?