UNIVERSITY OF SASKATCHEWAN
COLLEGE OF ENGINEERING

ELECTRICAL ENGINEERING EE271.3

Final Examination
Part B

Instructor: S.O. Kasap — December 18, 2002
Time allowed: Part B is nominally $1^1/_2$ hour.
Total time allowed: 3 hours for Parts A *and* B.

Instructions: Open book examination. The course textbook *and* one three-ring type binder of any size containing student-selection of notes and course material are allowed. Calculators are also allowed.

Answer any 3 questions from 5 questions. If you answer more than 3 questions, only the first three will be marked. All questions carry equal marks. All answers must be given in conventional units. State clearly all assumptions made in your derivations. Method of solution must be clearly shown. Numerical mistakes, incorrect, unconventional or missing units will be heavily penalized. Mention the source of materials data used.

Important: You must hand in Part A before you can start Part B. Write your answers in the university answer book.

Note: You may spend more or less time on Part B; but the total exam time is 3 hours.

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[3] **1. a** KCl has the same crystal structure as NaCl. The lattice parameter a of KCl is 0.629 nm. The atomic masses of K and Cl are 39.10 g mol^{-1} and 35.45 g mol^{-1} respectively. Calculate the density of KCl.

[6] **b** Calculate the specific heat capacity of a 62 wt.% Sn and 38 wt. %Pb solder given the atomic masses118.7 and 207.2 g mol^{-1} for Sn and Pb respectively.

[8] **c** A cold worked Al-alloy component takes 200 minutes to recrytallize at 250 °C but takes 14 minutes at 276 °C. How long will the recrystallization take place at 320 °C. Can you cold work or strain harden this component at 320 °C? Why can't you cold work Pb and Sn at room temperature?

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[7] **2. a** Consider a copper wire with a diameter of 5 mm that is carrying a current of 4 A at room temperature.

(i) Calculate the drift velocity of the conduction electrons. How does this compare with the mean velocity of the conduction electrons?

(ii) Calculate the mean free time between collisions (*i.e.* average time it takes for an electron to travel from one collision to another collision with a vibrating metal ion). What would happen to this mean free time if we were to add impurities into this metal?

(iii) Calculate the Joule heating of the wire per unit volume as W per mm^3 at 20 °C.

(iii) Calculate the Joule heating per unit volume at 50 °C.

[10] **b** A bronze component has the composition 94wt.%Cu-6wt.%Sn. Calculate its resistivity (ρ), and thermal conductivity (κ) and estimate its TCR (α) all at 20 °C.

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3. Consider a spherical pressure vessel that is to be used in aerospace applications; for example, storing high pressure hydrogen gas for a fuel cell. The stress σ in the wall is related to the pressure p in the vessel by

$$\sigma = \frac{pr}{2t} \tag{3.1}$$

where r is the outer radius and t is the wall thickness as shown in Figure Q.3.. The mass M of the vessel is

$$M = 4\pi r^2 t\rho \tag{3.2}$$

where ρ is the density. The stress σ in the wall will always have to satisfy

$$\sigma \le \frac{\sigma_{YS}}{S} \tag{3.3}$$

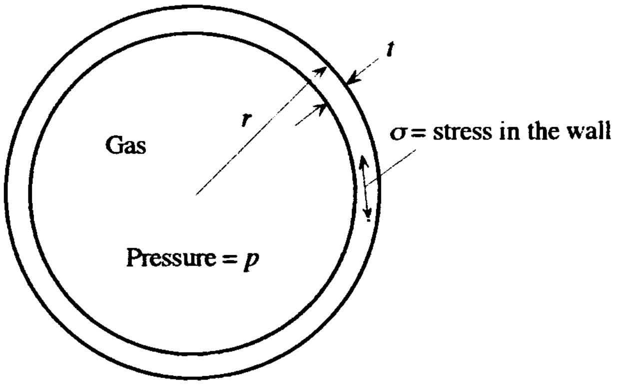
where S is a design safety factor.

[5] **a** Show that the *minimum mass* of the pressure vessel will be

$$M_{min} = 2S\pi pr^3 (\frac{\rho}{\sigma_{YS}}) \tag{3.4}$$

[6] **b** Table Q.3 shows various materials as candidates for the vessel. By making an appropriate table, decide which material will produce the lightest vessel?

[6] **c** Make a relative cost table for the vessel based on the materials in Table Q.3 and hence select the material for the minimum cost vessel.



Pressure vessel (schematic sketch)

Figure Q.3

TABLE Q.3: Properties of four candidate materials for a pressure vessel
[Note: 1 tonne = 1000kg; $1 g.cm^{-3} = 1 Mg m^{-3} = 10^3 kg.m^{-3}$; 1 UK£ ≈ 2.5 Cnd$]

MATERIAL	Density	Elastic Modulus, E	Yield Strength, σ_{YS}	Price (Yesterday's)
	($g.cm^{-3}$)	(GPa)	(MPa)	(UK£/tonne)
Mild steel	7.8	207	220	200
High strength steel alloy	7.8	207	400	950
Aluminum alloy	2.7	69	193	1,000
GFRP (Glass fiber	1.8	15	75	1,300

[17] 4. A device engineer fabricates a metal-semiconductor diode. The metal is a thin film of Al (not necessarily pure Al) on a Si crystal wafer. Suppose that the Al film is 0.15 μm thick and the Si crystal wafer is 300 μm thick. Estimate the temperature induced *total strain* in the Al film if the device is taken from 25 °C down to –60 °C. What is the stress if the deformation were elastic? The yield strength of this Al-alloy is 50 MPa. What is the mechanical strain that results in yield (plastic deformation)? What is the mechanical strain in the Al film? What is the stress in the Al film? Do you think the deformation of the Al thin film is elastic? Estimate the temperature at which the Al film begins to deform plastically (reaches the yield point)?

Over the temperature range of interest aluminum has a thermal expansion coefficient of about 10×10^{-6} K^{-1} and silicon has a thermal expansion coefficient of about 1×10^{-6} K^{-1}. The elastic modulus of Al is 70 GPa.

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5. A power transistor with maximum power rating of 25 W has a maximum junction temperature of 140 °C. (Maximum rated power refers to the transistor case at 25 °C.)

[4] a What is the required thermal resistance between the case and the ambient for operation at maximum rated power?

[3] b What is the required thermal resistance from case to ambient if the transistor is to be operated at 20 W?

[10] c The transistor is mounted on a heat sink using a mica washer (an electrical insulator) and thermal paste (grease). The heat sink has a thermal resistance of 2.3 °C/W. The thermal resistance of the mica and the thermal paste together is 0.4 °C /W. The power amplifier circuit using this transistor is to be placed in a box in which the maximum ambient temperature is expected to reach 60 °C. What is the maximum power that can be dissipated by the transistor?

PHYSICAL CONSTANTS AND USEFUL INFORMATION

$c = 2.9979 \times 10^{8}$ m s^{-1}

$e = 1.6021 \times 10^{-19}$ C

$m_e = 9.1091 \times 10^{-31}$ kg

$h = 6.62608 \times 10^{-34}$ J s

$N_A = 6.0221 \times 10^{23}$ mol^{-1}

$k = 1.3807 \times 10^{-23}$ J K^{-1}

$\varepsilon_o = 8.8542 \times 10^{-12}$ F m^{-1}

$\mu_o = 4\pi \times 10^{-7}$ H m^{-1}

$\hbar = h/(2\pi) = 1.05459 \times 10^{-31}$ J s

Gas constant, $R = N_A k =$ 8.3144 J K^{-1} mol^{-1} = 0.083144 L.bar K^{-1} mol^{-1}

Mass of proton = 1.67495×10^{-27} kg

Mass of hydrogen atom = 1.6736×10^{-27} kg

Acceleration due to gravity (at 45° latitude), g =9.81 m s^{-2}

UNITS

SI UNITS

Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K

DERIVED SI UNITS

Electric charge	coulomb	C = A s
Electrical resistance	ohm	$\Omega = V/A = kg\ m^2\ A^{-2}\ s^{-3}$
Electrical conductance	siemen	$S = 1/\Omega$
Electrical capacitance	farad	$F = A\ s\ V^{-1} = A^2\ s^4\ kg^{-1}\ m^{-2}$
Electrical inductance	henry	$H = V\ s\ A^{-1} = kg\ m^2\ s^{-1}\ A^{-2}$
Energy	joule	$J = kg\ m^2\ s^{-2} = N\ m$
Force	newton	$N = kg\ m\ s^{-2}$
Magnetic flux	weber	$Wb = V\ s = kg\ m^2\ A^{-1}\ s^{-2}$
Magnetic flux density	tesla	$T = Wb\ m^{-2} = V\ s\ m^{-2} = kg\ A^{-1}\ s^{-2}$
Pressure	pascal	$Pa = N\ m^{-2}$
Power	watt	$W = J\ s^{-1} = kg\ m^2\ s^{-3}$
Electric potential difference	volt	$V = N\ m\ C^{-1} = kg\ m^2\ s^{-3}\ A^{-1}$
Frequency	hertz	$Hz = s^{-1}$

SOME CONVERSION FACTORS

LENGTH

1m = 39.37in = 3.280ft = 6.2137×10^{-4}miles

1 in = 0.0254m

ENERGY

1 kJ mole^{-1} = 0.2389 kcal mol^{-1} = 0.010363 eV atom^{-1}

1 kcal mole^{-1}= 4.1840 kJ mol^{-1} = 0.043360 eV atom^{-1}

1 eV atom^{-1} = 96.490 kJ mol^{-1} = 23.062 kcal mol^{-1}

1 ft lb = 1.356 J   1 BTU = 1055 J

1 erg = 10^{-7} J   1 kWh = 3.600×10^6 J

FORCE

1 N =0.2248 lb   1 lb = 4.448 N

PRESSURE

1 Pa =1 N.m^{-2} =1.45×10^{-4} psi = 9.869×10^{-6} atm.

1 atm. = 1.013×10^5 Pa = 1.01325 bar = 760 torr (mm Hg)

1 psi = 6.895×10^3 Pa