THE UNIVERSITY OF MELBOURNE

SEMESTER TWO ASSESSMENT 2001

Department: SCHOOL OF PHYSICS
Subject Number 640-381
Subject Name: PRINCIPLES & APPLICATIONS OF SENSORS

Time allowed: 3 Hours
Reading time allowed: 15 minutes
This paper has 7 pages

Authorised materials:

Calculators are permitted in accordance with the rules of the Faculty of Science. They should not have been programmed nor should they store additional information.

Instructions to Invigilators:

The exam paper may be retained by the students.

Instructions to Students:

Attempt **ALL** questions. Total marks = 100.

Paper to be held by the Baillieu Library.

Question 1: (13 marks)

a. What is the difference between a sensor and a transducer? Can a device be both a sensor and a transducer? If so, give an example of such a device.

(5 marks)

b. An important characteristic of a sensor is its transfer function, V= f(s) where s is the stimulus and V is the electrical signal.

In terms of the transfer function, what is the sensitivity of a sensor?

(2 marks)

c. The capacitance of a cylinder of height H partially immersed in liquid is:

$$C = 2\pi\varepsilon_0 [H - h(1-\kappa)] / \ln b/a$$

Here b is the outer diameter of the cylinder, a is the inner diameter, κ is the dielectric constant of the liquid in which the cylinder is immersed and h is the level to which the cylinder is immersed in the liquid (ie h=0 is completely out of the water, h=H is completely immersed)

i. If h = 2 cm, H = 20 cm, $\varepsilon_0 = 8.85\ 10^{-12}\ C^2/Nm^2$, a = 1 mm, b = 2 mm, κ (water) = 78.5, what is the capacitance of the cylinder?

ii. The sensor is to be used to measure the height of fluid. Discuss the performance of this sensor for this purpose. Is the transfer function linear? Is the sensitivity the same regardless of the fluid height? Give an expression for the sensitivity.

(2+4 = 6 marks)

Some data for questions 2, 3 and 4 follows:

Capacitance $C = \dfrac{A\varepsilon}{d}$,

Charge Q = C V,

Resistance R = ρ~~A/l~~ ρ l/A

Charge from a Piezoelectric effect Q= d F

Charge from the Pyroelectric effect. $Q = P_Q A \Delta T$

Seebeck-Peltier effect: $\dfrac{dV}{dT} = \alpha \dfrac{dT}{dx}$

$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m

$\mu_0 = 4\pi \times 10^{-7}$ H/m

Stress = Force/Unit Area

Strain = Δl/l

Young's Modulus Y = Stress/Strain

(For $BaTiO_3$, $\varepsilon_r = 1700$, d = 78 pC/N, $P_Q = 4 \times 10^{-4}$ $C.m^{-2}K^{-1}$)

(For PVDF, $\varepsilon_r = 12$, d = -30 pC/N, $P_Q = 0.4 \times 10^{-4}$ $C.m^{-2}K^{-1}$)

(For Al $Y = 70 \times 10^{9}$ $N.m^{-2}$, resistivity $\rho = 2.75 \times 10^{-8}$ Ωm)

(For Cu resistivity $\rho = 1.69 \times 10^{-8}$ Ωm)

Assume g= 10 ms^{-2}

Question 2: (16 Marks)

a. Explain how a Pyroelectric electric sensor differs from one that employs the Peltier effect. Include in you answer a description of the different physical processes used in each sensor.

(6 marks)

b. Describe two other uses of the Peltier effect additional to being used as a temperature sensor.

(4 marks)

c. A 1 mm thick $BaTiO_3$ pyroelectric sensor is subject to a 50 K temperature flux. What voltage does it generate?

(4 marks)

d. If the same voltage was generated by a PVDF sensor of the same dimensions, what temperature change would that represent?

(2 marks)

Question 3 (14 marks)

a. Briefly explain the physical processes that make a Piezoelectric sensor work.

(5 marks)

b. Derive a formula that relates the magnitude of the force F applied to a piezo-electric sensor of cross sectional area A and thickness d to the voltage generated across the sensors surface.

(4 marks)

c. A 1 mm thick piezoelectric sensor with an area of 1 cm ×1 cm, develops a voltage of 1.6 kV. If the sensor is made of PVDF, what weight is being applied to the sensor?

(3 marks)

d. What voltage would the same load generate if the sensor were made of $BaTiO_3$?

(2 marks)

Question 4: (20 Marks.)

An 80 kg mass is hung from the end of a 30 cm long aluminium (Al) cylinder of whose radius is 1 cm before the load is applied. The diameter of the Al cylinder is monitored by a piezoresitive sensor, consisting of an insulated 0.5 mm radius copper wire wrapped once around the cylinder.

a. Derive a formula relating the diameter of the Al cylinder to the suspended load.

(6 marks)

b. Using your result from (a) derive a formula relating the resistance of the copper wire to the suspended load.

(4 marks)

c. What is the change in resistance of the Cu wire sensor due to the suspended load?

(4 marks)

d. What is the sensitivity of the Cu sensor to the suspended load?

(3 marks)

e. What would be the sensitivity of a sensor consisting of 10 loops of copper wire to a suspended load?

(3 marks)

The following formulae and constants may be useful for questions 5 and 6

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$$

$$hf = KE + \phi$$

$$E_n = -\frac{E_0 Z^2}{n^2}$$, with E_0 = 13.6 eV

$R = \sigma T^4$ with $\sigma = 5.67 \times 10^{-8}$ W m^{-2}K^{-4}

$\lambda_{max}T = 2.898 \times 10^{-3}$ mK

$\lambda = h/p$

$2\, d \sin\sigma = n\, \lambda$

c = 3.00×10^{8} m.s^{-1}
g = 9.8 m/s^2
R = 1.097×10^{7} m^{-1}
h = 6.63×10^{-34}J.s
e = 1.6×10^{-19} C
1 eV = 1.6×10^{-19} J
m_e = 9.11×10^{-31}kg
k_B = 1.381×10^{-23} J/K
0^0C = 273K

Question 5: (19 marks)

(a) A naked person is standing in a room which is held at 20^0C. Assume the person acts as a black body with a surface area of 1.4m^2 and a surface temperature of 33^0C.

(i) At what wavelength does the emission from the person have its maximum intensity?
(ii) Calculate the net loss of energy (in kW) from the person.
(iii) Explain how one could design an imaging system to detect persons in a completely darkened room.

(7 marks)

(b) In order to maximize the intensity of electrons emitted by the photoelectric effect, surfaces can be coated with materials possessing a low work function. The minimum work function that can be achieved by such coatings is, in practice, about 1.5 eV.

(i) What is the maximum wavelength of light that will result in photoemission from such a surface?

(ii) Can the photoelectric effect be used to detect photons used in optical fibre communications with $\lambda = 1.55\ \mu m$? If not, how can such photons be detected?

(3+4 = 7 marks)

(c) One of the simplest models of molecular structure envisages the atoms joined by forces that act as the 'atomic springs' Briefly describe a method by which the force constant of these 'springs' can be measured.

(5 marks)

Question 6: (18 marks)

(a) Describe the operation of the atomic absorption spectrometer.

Your answer should include:

(i) a basic description of the machine.

(ii) a description of the physical principles that underpin its operation.

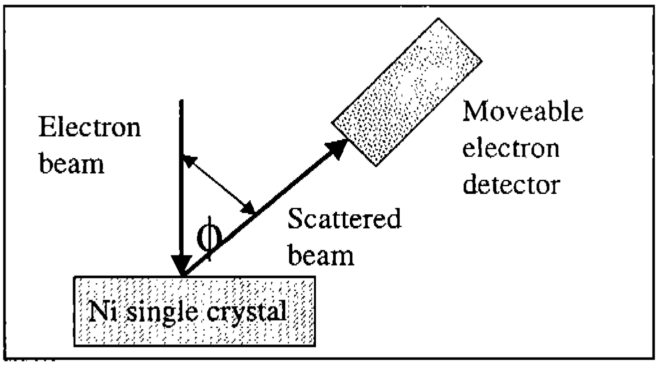
(iii) A comment on the sensitivity that is typically achievable?

(2+4+2 = 8 marks)

(b) Estimate the wavelength of the X-ray emitted from a Tantalum target when an electron makes a transition from the n=4 to n=1 state. Use Bohr's atomic theory and ignore screening effects. The atomic number of tantalum is 73.

(5 marks)

(c) Electrons are accelerated through a potential difference of 54V and are incident on a Ni target as shown. The lattice spacing of Ni is known from X-ray measurements to be 0.216nm. The entire arrangement is placed in a vacuum.



(i) What is the wavelength of these electrons?

(ii) The detector is scanned through a range of ϕ angles. At what value of ϕ will the electron detector record its maximum value?

(5 marks)

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