Problem sheet 2: electrical sensors

1 (2001 exam)

An 80 kg mass is hung from the end of a 30 cm long aluminium (Al) cylinder whose radius is 1 cm before the load is applied. The diameter of the Al cylinder is monitored by a piezoresistive 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.
(b) Using your result from (a), derive a formula relating the resistance of the copper wire to the suspended load.
(c) What is the change in resistance of the Cu wire sensor due to the suspended load?
(d) What is the sensitivity of the Cu sensor to the suspended load?
(e) What would be the sensitivity of a sensor consisting of 10 loops of copper wire to the suspended load?

Data:

Al: $Y = 7 \times 10^{10}$ N/m^2
$\rho = 2.75 \times 10^{-8}$ Ωm

Cu: $\rho = 1.69 \times 10^{-8}$ Ωm

2 (2001 exam)

(a) Explain how a pyroelectric sensor differs from one that employs the Seebeck-Peltier effect. Include in your answer a descriptin of the different physical processes used in each sensor.
(b) Describe two other uses of the Seebeck-Peltier effect additional to being used as a temperature sensor.
(c) A 1 mm thick $BaTiO_3$ pyroelectric sensor is subject to a 50 K temperature flux. What voltage does it generate?
(d) If the same voltage was generated by a PVDF sensor of the same dimensions, what temperature change would this represent?

Data:

$C=\varepsilon A/d$
$dV/dT = \alpha\ dT/dx$

$Q= CV$ for a capacitor
$Q=d F$ Piezoelectric effect
$Q=P_Q A\Delta T$ Pyroelectric effect

$BaTiO_3$: $\varepsilon_r = 1700$

$d = 78$ pC/N

$P_Q = 4 \times 10^{-4}$ C/m^{2}K

PVDF: $\varepsilon_r = 1700$ (?)

$d = -30$ pC/N

$P_Q = 0.4 \times 10^{-4}$ C/m^{2}K

3 (2001 exam)

(a) Briefly describe the physical processes that make a piezoelectric sensor work.
(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 sensor's surface.
(c) A 1 mm thick piezoelectric sensor with an area of 1 cm x 1 cm develops a voltage of 1.6 kV. If the sensor is made of PVDF, what weight is being applied to the sensor?
(d) What voltage would the same load generate if the sensor were made of $BaTiO_3$?

Data: use the data from the previous questions.

4 (2004 exam)

(a)
  (i) What is the difference between piezoelectric and pyroelectric sensors? Include a simple sketch.
  (ii) Give an example of a sensing application for each type of sensor.

(b) A pyroelectric force sensor is constructed from a 1 mm thick piece of $BaTiO_3$ with an electrode area of 1 cm^2.
  (i) If a force of 0.5 N is applied to the sensor, what change will develop on the electrodes?

  (ii) What voltage will be generated on the electrodes as a result of this charge?

  (iii) What is the sensitivity of this sensor?

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(a) The resistivity of metals, and thus resistance, varies with temperature according to:

$\rho = \rho_0 [1 + \alpha (T - T_0)]$

At $T_0 = 293$ K, $\rho_0 = 1.69$ μΩ.cm.

A secondary thermometric standard for measuring temperature in the range 14 - 900 K on the international temperature scale is a platinum resistance thermometer (for Pt, $\alpha = 3.9 \times 10^{-3}$ K^{-1}).

For a Pt wire thermometer of diameter 0.1 mm and length 3 cm, what is the resistance at 14 K and at 900 K ?

b) A Pt resistive temperature detector (RTD) has a resistance given by.

$R = R_0 (1 + 39.08\text{x}10^{-4}\ T - 5.8\ 10_{-7}\ T_2)$

(where $R_0 = 100$ Ω. is the resistance at 0 °C).

What is the difference between the linear and second order resistance values at T = 150 °C? This is equivalent to how large an error in temperature?

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Consider heating a copper rod. Its resistance, length and cross-sectional area change upon heating.

(a) If the temperature changes by 1° C, what percentage changes occur in R, L and A? The thermal expansion coefficient of copper is 1.7×10^{-5} K^{-1}

(b) Comment on the implications of (a) for using a copper rod as a temperature sensor.

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What is the thermoelectric coefficient (also known as the differential Seebeck coefficient) for the following combinations?

(a) Copper/Aluminium

(b) Iron/Nickel

(c) P-type Si/n-type Si

What temperature change does a voltage of 12 mV represent in each case? Which sensor has the highest sensitivity?

Data:

Metal	α (μV/K)
Copper	0
Aluminium	-3.2
Iron	13.4
Nickel	-20.4
p-type Si	1000
n-type Si	-1000