Problem sheet 3: Mechanical sensors

1 (2002 exam)

(a) Explain the characteristics of:
   (i) An absolute pressure sensor
   (ii) A gage pressure sensor
   (iii) A differential pressure sensor

(b) The atmospheric pressure can fluctuate between 99 kPa and 102 kPa. If one used a U-tube barometer filled with mercury (Hg) to measure these pressures,
   (i) What would be the height difference measured at the maximum pressure?
   (ii) What would be the height difference measured at the minimum pressure?
   (iii) Is this a good sensor for this kind of measurement? Explain your answer.
   (iv) What is the sensitivity of the U-tube barometer?
   (v) How could the sensitivity of the sensor be improved?

Data: $\rho_{Hg} = 1.3595 \times 10^4$ kg/m^3

2 (2004 exam)

(a) A steam furnace operates in a pressure range of 10-15 atm. An open-tube manometer filled with mercury is used to measure the pressure inside the furnace.
   (i) If the pressure is 12.34 atm, what is the height difference in the manometer at maximum pressure? Include a diagram in your answer.
   (ii) Is this a good sensor for this application? Justify your answer.

(b) An ultrasonic Doppler flow meter ius commonly used to measure the flow speed of blood in arteries.
   (i) Outline the operation of an ultrasonic Doppler flow meter. Include a diagram.
   (ii) If the speed of sound in blood is 1500 m/s and the frequency of outgoing and incoming pulses ia 1.00 MHz and 1.05 MHz respectively, what is the speed of the blood? Assume that the transmitters are aligned at 15° to the artery of interest.

3 A simple mechanical device for measuring force is the spring, since the restoring force of the spring is linearly dependent on its extension (or compression). The restoring force of the spring is given simply by

$F = -kx$

where k is the spring constant of the spring. Such a device (i.e. a set of scales) is used to measure the weight of bananas at a supermarket. A number of bananas are suspended from the scales and the meter measures 2.3 kg, in the process the spring stretches 5.8 cm from its equilibrium extension.

(a) What is the weight of the bananas? ($g = 9.81$ m/s^2).
(b) What is the spring constant of the spring?
(c) A further 1.2 kg of bananas are added, what is the new extension of the spring (from equilibrium)?

4 Blood flow in the aorta (radius 1 cm) is laminar, with a Reynolds number of 1600.

Blood viscosity and density are, respectively, $\mu = 4 \times 10^{-3}$ Pa.s and $\rho = 1060$ kg/m^3.

(a) What is the blood velocity?

(b) If the blood velocity increases by a factor of 4, is the flow still laminar?

5 The flow velocity of a non-viscous fluid can be measured using the Venturi effect, where a pressure difference in the flow of the fluid corresponds directly to a velocity difference. The venture effect is encapsulated in the equation

$$P + \tfrac{1}{2} \rho v^2 = \text{constant}$$

Petrol flows through a horizontal cylindrical pipeline of radius 1 m at a pressure of 208 kPa. The pipe radius decreases, causing the petrol to flow faster; the pressure drops to 182 kPa.

(a) If the initial velocity was 4.3 m/s, what is the new velocity?

(b) Realising that the cross sectional area of the pipe multiplied by the velocity of the fluid is a constant, what must the radius of the new section of pipe be?

Data: the density of petrol is 0.68×10^3 kg/m^3.