Problems

2.1 The e.m.f. at a thermocouple junction is 645 μV at the steam point, 3375 μV at the zinc point and 9149 μV at the silver point. Given that the e.m.f.–temperature relationship is of the form $E(T) = a_1T + a_2T^2 + a_3T^3$ (T in °C), find a_1, a_2 and a_3.

2.2 The resistance $R(\theta)$ of a thermistor at temperature θ K is given by $R(\theta) = \alpha \exp(\beta/\theta)$. Given that the resistance at the ice point ($\theta = 273.15$ K) is 9.00 kΩ and the resistance at the steam point is 0.50 kΩ, find the resistance at 25 °C.

2.3 A displacement sensor has an input range of 0.0 to 3.0 cm and a standard supply voltage $V_S = 0.5$ volts. Using the calibration results given in the table, estimate:

(a) The maximum non-linearity as a percentage of f.s.d.
(b) The constants K_I, K_M associated with supply voltage variations.
(c) The slope K of the ideal straight line.

Displacement x cm	0.0	0.5	1.0	1.5	2.0	2.5	3.0
Output voltage millivolts ($V_S = 0.5$)	0.0	16.5	32.0	44.0	51.5	55.5	58.0
Output voltage millivolts ($V_S = 0.6$)	0.0	21.0	41.5	56.0	65.0	70.5	74.0

2.4 A liquid level sensor has an input range of 0 to 15 cm. Use the calibration results given in the table to estimate the maximum hysteresis as a percentage of f.s.d.

Level h cm	0.0	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0
Output volts h increasing	0.00	0.35	1.42	2.40	3.43	4.35	5.61	6.50	7.77	8.85	10.2
Output volts h decreasing	0.14	1.25	2.32	3.55	4.43	5.70	6.78	7.80	8.87	9.65	10.2

2.5 A repeatability test on a vortex flowmeter yielded the following 35 values of frequency corresponding to a constant flow rate of 1.4×10^{-2} m^3 s^{-1}: 208.6; 208.3; 208.7; 208.5; 208.8; 207.6; 208.9; 209.1; 208.2; 208.4; 208.1; 209.2; 209.6; 208.6; 208.5; 207.4; 210.2; 209.2; 208.7; 208.4; 207.7; 208.9; 208.7; 208.0; 209.0; 208.1; 209.3; 208.2; 208.6; 209.4; 207.6; 208.1; 208.8; 209.2; 209.7 Hz.

(a) Using equal intervals of width 0.5 Hz, plot a histogram of probability density values.
(b) Calculate the mean and standard deviation of the data.
(c) Sketch a normal probability density function with the mean and standard deviation calculated in (b) on the histogram drawn in (a).

2.6 A platinum resistance sensor is used to interpolate between the triple point of water (0 °C), the boiling point of water (100 °C) and the freezing point of zinc (419.6 °C). The corresponding resistance values are 100.0 Ω, 138.5 Ω and 253.7 Ω. The algebraic form of the interpolation equation is:

$$R_T = R_0(1 + \alpha T + \beta T^2)$$

where R_T Ω = resistance at T °C
R_0 Ω = resistance at 0 °C
α, β = constants.

Find the numerical form of the interpolation equation.

2.7 The following results were obtained when a pressure transducer was tested in a laboratory under the following conditions:

I Ambient temperature 20 °C, supply voltage 10 V (standard)
II Ambient temperature 20 °C, supply voltage 12 V
III Ambient temperature 25 °C, supply voltage 10 V

Input (barg)	0	2	4	6	8	10
Output (mA)						
I	4	7.2	10.4	13.6	16.8	20
II	4	8.4	12.8	17.2	21.6	28
III	6	9.2	12.4	15.6	18.8	22

(a) Determine the values of K_M, K_I, a and K associated with the generalised model equation $O = (K + K_M I_M)I + a + K_I I_I$.
(b) Predict an output value when the input is 5 barg, $V_S = 12$ V and ambient temperature is 25 °C.

Basic problems

2.8 A force sensor has an output range of 1 to 5 V corresponding to an input range of 0 to 2×10^5 N. Find the equation of the ideal straight line.

2.9 A differential pressure transmitter has an input range of 0 to 2×10^4 Pa and an output range of 4 to 20 mA. Find the equation to the ideal straight line.

2.10 A non-linear pressure sensor has an input range of 0 to 10 bar and an output range of 0 to 5 V. The output voltage at 4 bar is 2.20 V. Calculate the non-linearity in volts and as a percentage of span.

2.11 A non-linear temperature sensor has an input range of 0 to 400 °C and an output range of 0 to 20 mV. The output signal at 100 °C is 4.5 mV. Find the non-linearity at 100 °C in millivolts and as a percentage of span.

2.12 A thermocouple used between 0 and 500 °C has the following input–output characteristics:

Input T °C	0	100	200	300	500
Output E μV	0	5268	10 777	16 325	27 388

(a) Find the equation of the ideal straight line.
(b) Find the non-linearity at 100 °C and 300 °C in μV and as a percentage of f.s.d.

2.13 A force sensor has an input range of 0 to 10 kN and an output range of 0 to 5 V at a standard temperature of 20 °C. At 30 °C the output range is 0 to 5.5 V. Quantify this environmental effect.

2.14 A pressure transducer has an output range of 1.0 to 5.0 V at a standard temperature of 20 °C, and an output range of 1.2 to 5.2 V at 30 °C. Quantify this environmental effect.

2.15 A pressure transducer has an input range of 0 to 10^4 Pa and an output range of 4 to 20 mA at a standard ambient temperature of 20 °C. If the ambient temperature is increased to 30 °C, the range changes to 4.2 to 20.8 mA. Find the values of the environmental sensitivities K_I and K_M.

2.16 An analogue-to-digital converter has an input range of 0 to 5 V. Calculate the resolution error both as a voltage and as a percentage of f.s.d. if the output digital signal is:

(a) 8-bit binary
(b) 16-bit binary.

2.17 A level transducer has an output range of 0 to 10 V. For a 3 metre level, the output voltage for a falling level is 3.05 V and for a rising level 2.95 V. Find the hysteresis as a percentage of span.