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MECHANICAL ENGINEERING

CONVENTIONAL Practice Sets

CONTENTS

THERMODYNAMICS

1 CHAPTER
Basic Concepts and Zeroth Law of Thermodynamics

Practice Questions : Level-I

Q.1 A new scale X of temperature divided in such a way that the freezing point of ice is 110°X and the boiling point is 450°X. At what temperature both the Celsius and new temperature scale reading would be same?

Solution:

	°C	°X
BP →	100°C	450°X
FP →	0°C	110°X

$$\frac{C-0}{100-0} = \frac{X-110}{450-110}$$

$$\Rightarrow \quad 34\,C = 10X - 1100 \text{ (when } X = C)$$

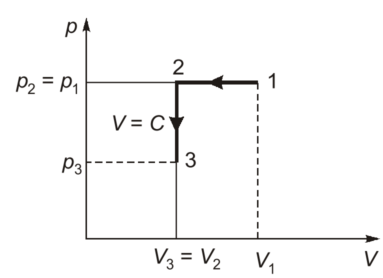
$$\Rightarrow \quad 24°C = -1100$$

$$\Rightarrow \quad C = -45.8°C$$

Q.2 A certain amount of an ideal gas is initially at a pressure p_1 and temperature T_1. First, it undergoes a constant pressure process 1-2 such that $T_2 = 3T_1/4$. Then, it undergoes a constant volume process 2-3 such that $T_3 = T_1/2$. What is the ratio of the final volume to the initial volume of the ideal gas?

Solution:

Process 1 – 2: At $p = C$



$$T_2 = \frac{3T_1}{4} \quad \text{(given condition)}$$

or

$$\frac{T_2}{T_1} = \frac{3}{4}$$

According to Charle's law

$$\frac{V_2}{V_1} = \frac{T_2}{T_1} = \frac{3}{4}$$

Process 2 – 3: At $V = C$

$$T_3 = \frac{T_1}{2} \text{ given condition}$$

$$\frac{\text{Final volume}}{\text{Initial volume}} = \frac{V_3}{V_1} = \frac{V_2}{V_1} = \frac{T_2}{T_1} \qquad (\because V_3 = V_2)$$

$$= \frac{3}{4} = \mathbf{0.75}$$

Q.3 The relationship of resistance R in ohm and temperature T in kelvin for a thermistor is given by: $R = R_0 e^{\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]}$ where R_0 is the resistance in ohms measured at temperature. T_0K and b is the material constant with units of K

For a particular case, $R_0 = 2.2\ \Omega$ at $T_0 = 310$ K

And $R = 0.31\Omega$ at $T = 422$ K

Determine the material constant β and hence find the resistance at 373 K and 273 K.

Solution:

The equation for the thermistor is given by

$$R = R_0 e^{\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]}$$

where, $R_0 = 2.2\ \Omega$ and $T_0 = 310$ K

Since, $R = 0.21\ \Omega$ at $T = 422$ K

$$0.31 = 2.2e^{\left[\beta\left(\frac{1}{422} - \frac{1}{310}\right)\right]}$$

or $$0.31 = 2.2e^{[-8.5613 \times 10^{-4}\beta]}$$

Therefore, $$\beta = \frac{\log e^{\left(\frac{0.31}{2.2}\right)}}{-8.5613 \times 0^{-4}} = \frac{-1.95964}{-8.5613 \times 10^{-4}} = 2288.95/\text{K}$$

Thus resistance at $T = 373$ K

$$R_{373} = 2.2e^{\left[2288.95\left(\frac{1}{373} - \frac{1}{310}\right)\right]} = 2.2\ e^{-1.247} = \mathbf{0.632\ \Omega}$$

and at $T = 273$ K $$R_{273} = 2.2e^{\left[2288.95\left(\frac{1}{273} - \frac{1}{310}\right)\right]} = 2.2e^{1.0007226} = \mathbf{5.9845\ \Omega}$$

Q.4 The gas in system received heat which causes expansion against at a constant pressure of 2 bar. An agitator in the system is driven by an electric motor. Using 100 W for 4 kJ of heat supplied the volume increase of the system in 30 sec is 0.06 m^3. Estimate net change in the energy of the system.

Solution:

Given data: Pressure, $p = 2$ bar; Rating of motor = 100 W

Heat supplied, $Q = 4$ kJ; Duration of heat supply = 30 sec

Volume increase of the system, $\Delta V = 0.06$ m^3

Displacement work done of gas = $\int pdV = 2 \times 10^2 \times 0.06 = 12$ kJ (positive work)

Work done by motor = $100 \times 30 = 3$ kJ (negative work)

Net work done by the system upon the surroundings,

$$W = 12 - 3 = 9 \text{ kJ}$$

As per 1st law of thermodynamics:

$$Q_s = W + \Delta U$$

$$\Delta U = Q_s - W = 4 - 9 = -5 \text{ kJ}$$

The –ve sign indicates that energy of the system decreases

Practice Questions : Level-II

Q.5 The Van der Waals equation is given by $\left(p+\frac{a}{v}\right)(v-b)=RT$, where a and b are constant and other terms have usual meanings. Determine the work done in a reversible isothermal expansion.

Solution:

The Van der Waals equation is

$$\left(p+\frac{a}{v}\right)(v-b) = RT$$

It can be rearranged as $p = \frac{RT}{v-b} - \frac{a}{v}$

The work done by the gas can be calculated as

$$w = \int_{v_1}^{v_2} p\,dv = RT\int_{v_1}^{v_2}\frac{1}{v-b}dv - \int_{v_1}^{v_2}\frac{a}{v}dv = RT\ln\left(\frac{v_2-b}{v_1-b}\right) + a\ln\left[\frac{v_2}{v_1}\right]$$

Q.6 The readings of two thermometers A and B agree at ice point and steam point as 0°C and 100°C. The two temperature readings are related by the following expression:

$$t_A = a + bt_B + ct_B^2$$

where a, b and c are constants. In a constant temperature bath, the temperature are shown as 51°C on thermometer A and 50°C on thermometer B. Determine the reading on thermometer B when the thermometer A reads 65°C. Can you comment which of the two thermometers is correct?

Solution:

Given: $t_A = a + bt_B + ct_B^2$

As the reading of two thermometers A and B agree at ice point (0°C) and steam point (100°C).

When t_A = 0°C, t_B is also 0°C

$$= a + bt_B + ct_B^2$$

$$0 = a + b(0) + c(0)^2$$

$$a = 0$$

So, $t_A = bt_B + ct_B^2$

when, t_A = 100°C, t_B is also 100°C

$$100 = b(100) + c(100)^2$$

$$b + (100)c = 1 \quad \text{... (i)}$$

when, t_B = 50°C, t_A = 51°C

$$t_A = bt_B + ct_B^2$$

$$51 = (50)b + (50)^2c \quad \text{... (ii)}$$

From equations (i) and (ii), we get $b = 1.04$

$$c = -4 \times 10^{-4}$$

$\therefore$ $t_A = 1.04\, t_B - 4 \times 10^{-4}\, t_B^2$

when, t_A reads 65°C $65 = 1.04t_B - 4 \times 10^{-4}\, t_B^2$

or $t_B = 64.07$°C

None of the two thermometers are ideal. So we cannot comment on to which is more correct.