1.10 EXERCISES

Nature of heat

Ex 1.10.1. In a Joule experiment 1 kg of liquid water in a 200 g copper container is stirred by flywheels when two masses each weighing 5 kg drop by a height of 1.5 m. Assuming that all heat generated by the resistance against the motion of the flywheel goes in raising the temperature of the water and the container, what will be the rise in the temperature? Assume that the kinetic energy of masses do not increase much during the fall.

Ex 1.10.2. A 30-hp motor is to rotate the paddles in the Joule mechanical equivalent of heat experiment. Assuming the electrical energy supplied to the motor ends up heating 3 kg of water initially at 20°C. How long the motor must run for the temperature to rise to 21°C?

Ex 1.10.3. A heating element has a resistance (R) of 2 Ohms(Ω). When a current I passes through a conductor of resistance R, the conductor uses energy at a rate of I^2R. The heating element is placed in 500 cm^3 of liquid water at 20°C in a Dewar flask, and a current of 2.5 amperes of current is passed for 30 sec. Find the final temperature of water. (Units: 1 A^2.Ω = 1 W.)

Temperature Scales and Thermometer

Ex 1.10.4. The temperature on a nice day in Missouri, USA is 65°F. What will be the readings in the Celsius and Kelvin scales?

Ex 1.10.5. The temperature on a hot day in Kolkata, India is 42°C. What will be the readings in the Fahrenheit and Kelvin scales?

Ex 1.10.6. In an experiment, the temperature of a copper plate is reported to change from 375.00 K to 375.25 K. How would you describe the same result in Celsius and Fahrenheit scales?

Ex 1.10.7. The resistance of a thin platinum wire is to be used as an indicator of temperature. It is found that the wire has a resistance of 1.50 Ω at the triple point. What is the temperature of a liquid when the resistance of the same wire is 1.55 Ω when immersed in the liquid?

Ex 1.10.8. A mercury Thermometer is to be calibrated using the triple point of water. The volume of mercury in the bulb is 1.0 cm^3 at the triple point of water. When the bulb containing mercury is dipped inside a warm liquid its volume expands with the following rule.

$$\frac{\Delta V}{V} = \left(1.8 \times 10^{-4} \text{ per } ^\circ\text{C}\right)(t - t_{tp})$$

As the volume expands, mercury is squeezed into a thin cylindrical pipe of diameter 0.2 mm attached to the bulb. Find the height in the cylindrical pipe the mercury will rise when the temperature of the fluid is 15°C. (Ignore any change in the volume of the bulb itself.)

Ex 1.10.9. A mercury Thermometer is to be calibrated using the triple point of water. The volume of mercury in the bulb is 1.0 cm^3 at the triple point of water. When the bulb containing mercury is dipped inside a warm liquid its volume expands with the following rule.

$$\frac{\Delta V}{V} = \left(1.8 \times 10^{-4} \text{ per } ^\circ\text{C}\right)(t - t_{tp})$$

When the Thermometer bulb is placed in a hot coffee of temperature 60°C, it is found that the mercury rises by a height of 10 cm. Find the area of cross-section of the mercury tube above the bulb. (Ignore any change in the volume of the bulb itself.)

Ex 1.10.10. A new temperature scale X is proposed in which the freezing and boiling points of water are 10°X and 510°X respectively. Find the temperature reading in this scale corresponding to 60°C.

Ex 1.10.11. The **Rankine scale** is similar to the Kelvin scale in the sense that its zero is set at the Absolute zero, but one degree rise in Rankine scale is equal to one degree of Fahrenheit instead of one degree Celsius. Find the temperature in the Rankine scale corresponding to (a) 0°F, (b) 0°C, and (c) 300 K.

Constant Volume Gas Thermometer

Ex 1.10.12. Why do you think different gases in a constant volume gas Thermometer at the same pressure would give different temperature readings for the same water bath?

Ex 1.10.13. Why does the difference between gases in a constant gas Thermometer disappear when the bulb has low density of gases, or low pressure in the bulb?

Ex 1.10.14. A constant volume gas Thermometer filled with the Nitrogen gas has a pressure of 1500 Pa at the triple point of water. What is the temperature when the pressure is 1100 Pa?

Ex 1.10.15. A constant volume gas Thermometer filled with the helium gas has a pressure of 2000 Pa at the triple point of Nitrogen. What is the pressure reading when the bulb is dipped in a vessel at a temperature of 30°C?

Heat Transfer

Ex 1.10.16. Windows are a source of heat loss in the winter from a heated room. Consider a plane glass window of height 1 m, width 50 cm and thickness 3 mm. The temperature inside the house is maintained at 27°C. What is the rate of loss of energy by the heat conduction through the window on a day when the temperature outside is −5°C and the air is still? (Note if the air is not still, there will be greater loss of heat not accounted for by the conduction alone.)

Ex 1.10.17. How much energy is transferred in 20 seconds through a cylindrical steel rod of length 50 cm and diameter 4 cm that connects two heat baths, one at 580 K and the other at 380 K?

Ex 1.10.18. Two heat baths at temperatures 580 K and 380 K are connected by steel and copper rods attached end to end, each of length 50 cm and diameter 4 cm. The rods are insulated so that heat can flow only along its length. (a) What is the temperature at the point where the rods are joined? (b) Find the power flux.

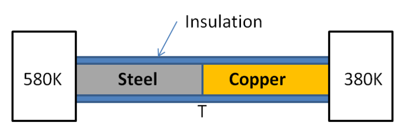

Figure 1.30: Exercise 1.10.18.

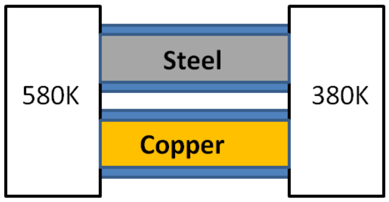

Figure 1.31: Exercise 1.10.19.

Ex 1.10.19. Two heat baths at temperatures 580 K and 380 K are connected by steel and copper rods parallel to each other, each of length 50 cm and diameter 4 cm. The rods are insulated so that heat can flow only along their lengths. Find the power flux through each rod and the net power flux.

Ex 1.10.20. How much energy is radiated in 10 sec by a black body of surface area 20 cm^2 when the body is maintained at 500 K?

Ex 1.10.21. An oven is heated to 600 K temperature. An orifice of diameter 4 mm is opened that lets the radiation to escape from the oven. Considering the oven to be a blackbody, find the rate at which the energy would be escaping the oven.

Ex 1.10.22. If 1400 Watts of power per square meter falls on the Earth from the Sun which is 150×10^6 km away. (a) What is the total power output of the Sun? (Assume power from the Sun radiates out symmetrically in all directions and drops as $1/r^2$ with the distance from the Sun.) (b) Assuming the Sun to be approximately a blackbody, determine the temperature at the surface of the Sun. (Radius of sun = 696,000,000 m).

Thermal Expansion and Stress

Ex 1.10.23. An aluminum and a copper bar each of length 1 m at 27°C are put in boiling water at 99°C. What is the difference in their lengths at 99°C?

Ex 1.10.24. A train track is made of long steel bars each of length 12 m at 20°C. The track is to operate between the temperatures of −5°C and 40°C. What gap should be placed between the tracks at 20°C so that the maximum separation between them does not exceed 5 cm and the minimum gap be zero in the given temperature range.

Ex 1.10.25. (a) Two copper plates each of length 15 cm and width 2 cm at temperature 25°C are placed parallel lengthwise on a wooden plank. There is a separation of 2 cm from one edge of one plate to the nearest edge of the other plate. They are then placed in an oven and heated to a temperature of 85°C. What is the separation between the plates at that temperature? (Ignore any change in the wooden plank.)

(b) A copper plate of length 15 cm and width 6 cm at temperature 25°C has a 2 cm wide cut in the middle which runs length wise almost to the end. The plate is then heated to a temperature of 85°C. How wide is the slit at 85°C? (Ignore any change in the wooden plank.).

(c) A copper plate of length 15 cm and width 6 cm at temperature 25°C has a 5 cm $\times$ 2 cm rectangular hole in the middle. The plate is then placed on a wooden plank, put in an oven and heated to a temperature of 85°C. How big is the hole at 85°C? (Ignore any change in the wooden plank.)

Ex 1.10.26. (a) A steel ball of spherical shape has a radius of 20 cm at 20°C. It is heated in an oven till its temperature is 400°C. What is the radius at 400°C? (b) A spherical shell of negligible thickness made of steel has a radius of 20 cm at 20°C. It is heated in an oven till its temperature is 400°C. What is the radius at 400°C?

Ex 1.10.27. A brass cylinder of length 1 m and area of cross-section 0.0025 m^2 fits snugly between two marble slabs fixed in two rigid walls when the temperature is 20°C. The brass is then heated to a temperature of 30°C. Find (a) the stress in brass, and (b) the force the brass cylinder exerts on one of the slabs assuming no expansion in the marble slabs or the walls. (Brass: $Y = 10^{11}$ N/m^2; $\alpha = 19{\times}10^{-6}$C^{-1}).

Ex 1.10.28. A steel wire of cross-sectional area $3.14{\times}10^{-6}$ m^2 is fixed to the concrete ceiling and a 2-kg mass is hung from the bottom. The length of the steel wire is found to be 1.2 m when the temperature in the room is 35°C. (a) What will be the length of the wire when the temperature is 0°C? (b) Find the tension in the wire when the temperature of the room is 0°C. (Steel: Y = 2×10^{11} N/m^2; $\alpha = 12 \times 10^{-6}$/C).

The Ideal Gas Law

Ex 1.10.29. An ideal gas occupies a container of volume 0.03 m^3 at 30°C and 10^5 Pa, how many molecules of the gas are there in the container?

Ex 1.10.30. What volume fraction of a 1 L of the Nitrogen gas is occupied by the molecules if the pressure is 1 atm and the temperature 27°C?

Ex 1.10.31. Find the pressure of one mole of the Nitrogen gas that occupies the volume 0.2 liters at the temperature 300 K using the following two different equations of state: (a) Ideal gas, and (b) van der Waals equation.

Ex 1.10.32. Find the pressure of one mole of the Oxygen gas that occupies the volume 20 liters at the temperature 300 K using the following two different equations of state:(a) Ideal gas, and (b) van der Waals equation.

Ex 1.10.33. Plot pV/nRT vs T for (a) hydrogen, (b) nitrogen, (c) oxygen, and (d) helium using van der Waals equation and using ideal gas law on the same graph. Interpret your observations.