SPECIFIC HEAT OF SOLIDS

Before moving to the practical let's see the basic terms and definition for proper understanding:

Specific Heat (Cv):

It is the amount of heat required to raise the temperature of a unit mass of a substance by one degree Celsius (or one Kelvin, as the difference in temperature is the same for all scales). It has the SI unit of joules per kilogram per kelvin $(\mathrm{J \cdot kg^{-1} \cdot K^{-1}})$.

Dulong-Petit Law:

He assumed particles as classical oscillators and the particles are vibrating independent of each other. He calculated the specific heat independent of the temperature as

$$C_v = 3R$$

where:
- R is the ideal gas constant

It was valid at high temperatures but failed at low temperatures.

Einstein Model:

It is proposed by Albert Einstein to explain the temperature dependence of specific heat with temperatures. He assumed particles as harmonic oscillators but they are oscillating independently of each other. He calculated the specific heat expression as:

$$C_V = 3Nk_B \left(\frac{\Theta_E}{T}\right)^2 \frac{e^{\Theta_E/T}}{(e^{\Theta_E/T} - 1)^2}$$

where:
- N is the number of atoms in the solid.
- k_B is the Boltzmann constant.
- Θ_E is the Einstein temperature, defined as $\Theta_E = \frac{h\nu}{k_B}$, with h Planck's constant and ν as frequency.

- T is the absolute temperature.

It was valid for high temperatures and failed at low temperatures. It showed that at low temperatures the graph is exponential which was not true.

Debye Model:

It is proposed by Peter debye to explain the temperature dependence of specific heat with temperatures. He assumed particles as harmonic oscillators and are oscillating with a range of frequencies and said that the atoms vibrate collectively. It introduces the concept of a Debye temperature T_D and gives the expression of specific heat as:

$$C_v = 9Nk\left(\frac{T}{T_D}\right)^3 \int_0^{T_D/T} \frac{x^4 e^x}{(e^x - 1)^2}\, dx$$

for temperatures below T_D. For high temperatures, it converges to the Dulong-Petit law.

EXPERIMENT 6

AIM: Plot Specific Heat of Solids w.r.t temperature for Dulong-Petit law, Einstein distribution function and Debye distribution function and compare them.

CODE:

```
import numpy as np
import matplotlib.pyplot as plt
from scipy.integrate import quad

N = 6e23  # Avogadro's number
h = 6.626e-34  # Planck's constant (J·s)
k = 1.38e-23  # Boltzmann's constant (J/K)
Te = 1240  # Einstein temperature in K
Td = 2400  # Debye temperature in K
T = np.arange(0, 2*Td + 1) # Temperature range

Cvdp = np.zeros_like(T, dtype=float)  # Dulong-Petit's law
Cve = np.zeros_like(T, dtype=float)  # Einstein's law
Cvd = np.zeros_like(T, dtype=float)  # Debye's law

for i, T_i in enumerate(T):
    Cvdp[i] = 3 * N * k  # Dulong-Petit's law

    if T_i == 0:
        Cve[i] = 0
        Cvd[i] = 0
    else:
        x = Te / T_i # Einstein's law
```

```
        Cve[i] = (3 * N * k * (x**2) * np.exp(x)) / ((np.exp(x) - 1)**2)

        if T_i > Td / 50:
            I, _ = quad(lambda y: (y**4 * np.exp(y)) / ((np.exp(y) - 1)**2), 0, Td
/ T_i)
            Cvd[i] = 9 * k * N * I * (T_i / Td)**3  # High temperature
        else:
            Cvd[i] = (12 * np.pi**4 / 5) * N * k * (T_i / Td)**3  # Low temp

# Plotting the graph
plt.plot(T, Cvdp, label="Dulong Petit", linewidth=2)
plt.plot(T, Cve, label="Einstein Law", linewidth=2)
plt.plot(T, Cvd, label="Debye Law", linewidth=2)
plt.title("Specific heat vs Temperature", fontsize=14)
plt.xlabel("Temperature (K)", fontsize=12)
plt.ylabel("Specific Heat (Cv)", fontsize=12)
plt.legend()
plt.show()
```

OUTPUT: