PHYS2627/PHYS2265 Introductory quantum physics

2265-1LABORATORYMANUAL

Experiment 1: Experiments of Thermal Radiation

I.Introduction

The electromagnetic radiation emitted by a body as a result of its temperature is called thermal radiation, which does not require an intervening medium to carry it. All bodies emit such radiation to their surroundings and absorb such radiation from them. When thermal equilibrium is reached the rates of emission and absorption are equal.

Thermal radiation ranges in wavelength from the longest infrared rays through the visible-light spectrum to the shortest ultraviolet rays. But even at temperatures as high as several thousand degrees Kelvin, over 90% of the emitted thermal radiation is invisible to us, being in the infrared part of the electromagnetic spectrum. Therefore, visible self-luminous bodies are quite hot. The intensity and distribution of radiant energy within this range is governed by the temperature of the emitting surface.

The spectral distribution of thermal radiation is specified by the quantity $R(\nu)$, called the spectral radiancy, which is defined so that $R(\nu)d\nu$ is equal to the energy emitted per unit time in radiation of frequency in the interval ν to $\nu + d\nu$ from an unit area of the surface at absolute temperature T. The integral of the spectral radiancy $R(\nu)$ over all ν is the total energy emitted per unit time per unit area from a body at temperature T. It is called the radiancy R_T,

$$R_T = \int_0^\infty R(\nu)d\nu$$

In fact, this result is called Stefan’s law, and it was first stated in 1879 in the form of empirical equation.

II.Experimental

A. **Radiation rates from different surface**
Equipment needed: radiation sensor, thermal radiation cube, window glass, millivoltmeter, ohmmeter.

1. Connect the ohmmeter and millivoltmeter as shown in Fig.1.1
2. Turn on the Thermal Radiation Cube and set the power switch to “HIGH”. Keep an eye on the ohmmeter reading. When it gets down to about 40 kΩ, reset the power switch to 5.0 (If the cube is preheated, just set the switch to 5.0)
3. When the cube reaches thermal equilibrium – the ohmmeter reading will fluctuate around a relatively fixed value – use the Radiation sensor to measure the radiation emitted from each of the four surfaces of the cube. Place the sensor so that the posts on its end are in contact with the cube surface (this ensures that the distance of the measurement is the same for all surfaces). Record your measurements and record the resistance of the thermistor. Use the conversion table provided to determine the corresponding temperature.Increase the power switch setting, first to 6.5, then to “HIGH”. At each setting, wait for the cube to reach thermal equilibrium, then repeat the measurements of step 3 and record your results in the appropriate table.

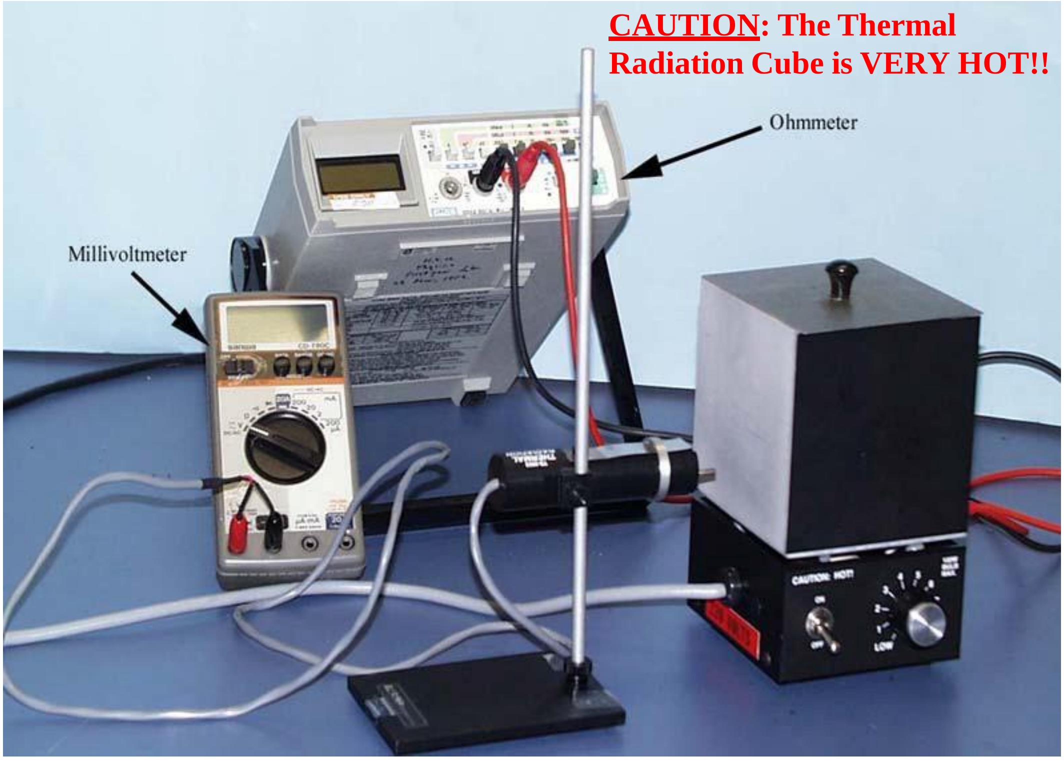

Figure 1.1

B. Absorption and Transmission of the Thermal Radiation

1. Place the Sensor approximately 5 cm from the black surface of the radiation cube and record the reading. Place a piece of window glass between the sensor and the cube. Does window glass effectively block thermal radiation?
2. Remove the lid of the Radiation Cube (or use the Stefan-Boltzmann Lamp) and repeat the measurements of step 1, but using the bare bulb instead of the black surface. Repeat with other transmission materials.

C. Inverse Square Law

Equipment needed: Radiation Sensor, Stefan-Boltzmann Lamp, Milli-voltmeter, Power Supply (12VDC 3A), Meter Stick.

1. Set up the equipment as shown in Fig. 2.1.
   a. Tape a meter stick to the table.Place the Stefan-Boltzmann Lamp at on end of the meter stick as shown.
   b. The zero point of the meter stick should align with the center of the lamp filament.
   c. Adjust the height of the Radiation Sensor so it is at the same level as the filament of the Stefan-Boltzmann Lamp.
   d. Align the lamp and sensor so that, as you slide the sensor along the meter stick, the axis of the lamp aligns as closely as possible with the axis of the sensor.
   e. Connect the sensor to the millivoltmeter and the lamp to the power supply as indicate in the figure.

2. With the lamp OFF, slide the sensor along the meter stick. Record the reading of the millivoltmeter at 10 cm intervals. Record your values in Table 2.1 on the data sheet. Average these values to determine the ambient level of thermal radiation. You will need to subtract this average ambient value from your measurements with the lamp on, in order to determine the contribution from the lamp alone.

3. Turn on the power supply to illuminate the lamp. Set the voltage to approximately 10 V.

IMPORTANT: Do not let the supply voltage to the lamp exceed 13V.

4. Adjust the distance between the sensor and the lamp to each of the settings listed in Table 2.2. At each setting, record the reading on the millivoltmeter.

IMPORTANT: Make each reading quickly. Between readings move the sensor away from the lamp, or place the reflective heat shield between the lamp and the sensor, so that the temperature of the sensor stays relatively constant.

5. Calculations
   a. For each value of X, calculate $1/X^2$. Enter your results in Table 2.2.
   b. Subtract the average ambient radiation level from each of your Rad measurements in Table 2.2. Enter your results in your Table.
   c. On the graph paper, make a graph of radiation level versus distance from source, using columns one and four from Table 2.2. Let the radiation level be the dependent (y) axis.
   d. If your graph from part c is not linear, make a graph of radiation level versus $1/X^2$, using columns three and four from Table 2.2.

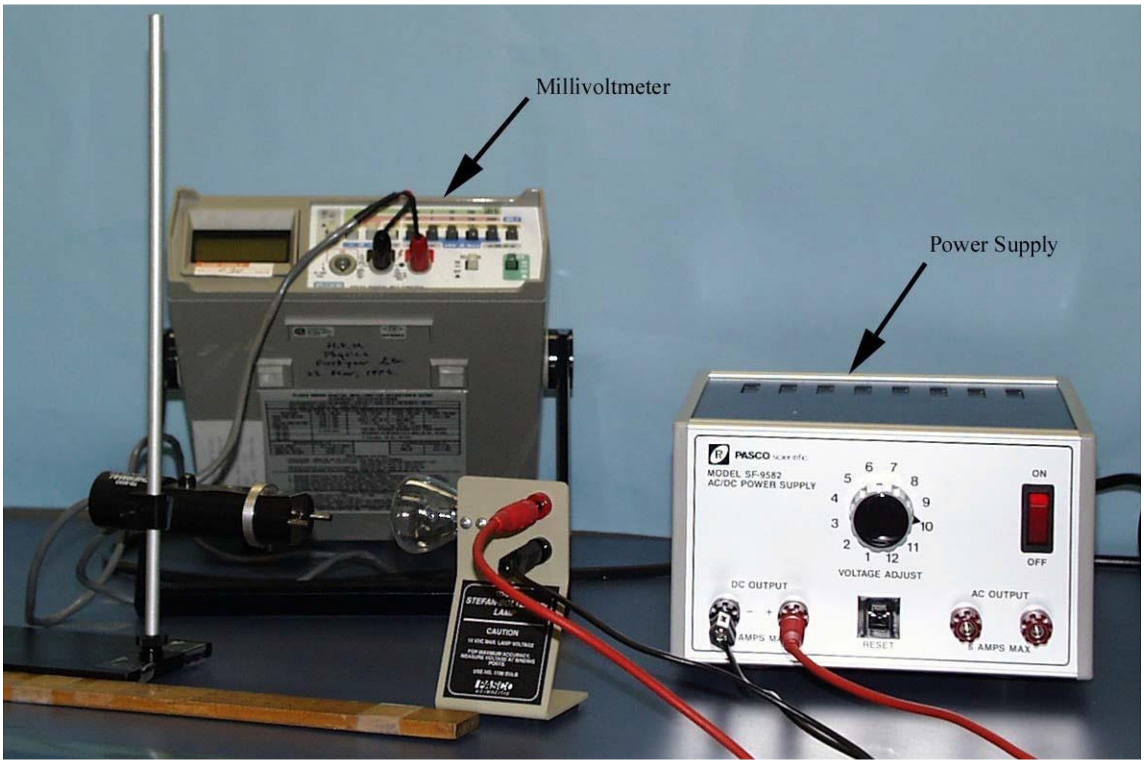

Figure 2.1

D. Stefan-Boltzmann Law

Equipment required: Radiation Sensor, Thermal Radiation Cube, Ohmmeter, Millivoltmeter, Thermometer.

The Stefan-Boltzmann Law relates R, the power per unit area radiated by an object, to T, the absolute temperature of the object. The equation is:

$$R = \sigma T^4; \left(\sigma = 5.6703 \times 10^{-8}\ \mathrm{W/m^2K^4}\right)$$

At those high temperatures (approximately 1000 to 3000K), the ambient temperature is small enough that it can be neglected in the analysis. In this experiment you will investigate the Stefan-Boltzmann relationship at much lower temperature using the Thermal Radiation Cube. At these lower temperatures, the ambient temperature cannot be ignored.

If the detector in the Radiation Sensor were operating at absolute zero temperature, it would produce a voltage directly proportional to the intensity of the radiation that strikes the detector minus the radiation leaving it. Mathematically, the sensor voltage is proportional to the sensor voltage is proportional to

$$R = R_{rad} - R_{det} = \sigma\,(T^4 - T_{det}^{\,4}).$$

As long as you are careful to shield the Radiation Cube when measurements are not being taken, T_{det} will be very close to room temperature (T_{rm}).

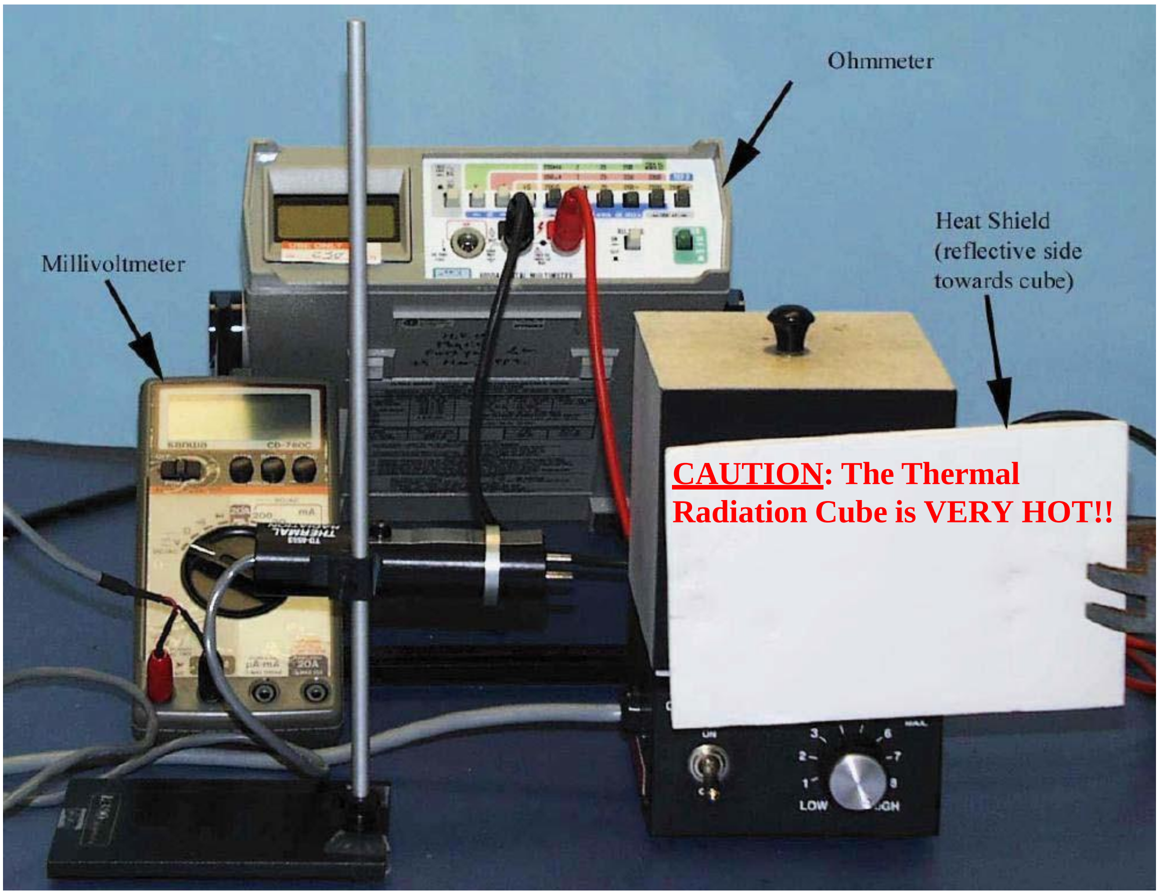

Figure 3.1

Procedure

1. Set up the equipment as shown in fig. 3.1. The Radiation Sensor should be pointed directly at the center of one of the better radiating surfaces of the cube (the black or white surface). The face of the sensor should be parallel with the surface of the cube and about 3 to 4 cm away.
2. With the Thermal Radiation Cube off, measure r_{rm}, the resistance at room temperature. Enter this data in the appropriate space on the sheet.
3. Shield the sensor from the cube using the reflecting heat shield, with the reflective side of the shield facing the cube.
4. Turn on the Thermal Radiation Cube and set the power switch to 10 or MAX.
5. Record the reading of the millivoltmeter at 10°C intervals in Table 3.1.

Calculations:

1. Using the table on the base of the Thermal Radiation Cube, determine T_c, the temperature in degrees Centigrade corresponding to each of your thermistor resistance measurements. For each value of T_c, determine T_k, the corresponding value in degrees Kelvin (K=°C +273). Enter both sets of values in Table 3.1, above. In the same manner, determine the room temperature, T_{rm}.
2. Calculate T_k^4 for each value of T_k and record the values in the table.
3. Calculate $T_k^4 - T_{rm}^4$ for each value of T_k and record your results in the table.
4. On separate sheet of paper, construct a graph of Rad versus $T_k^4 - T_{rm}^4$. Use Rad as the dependent variable (y-axis).