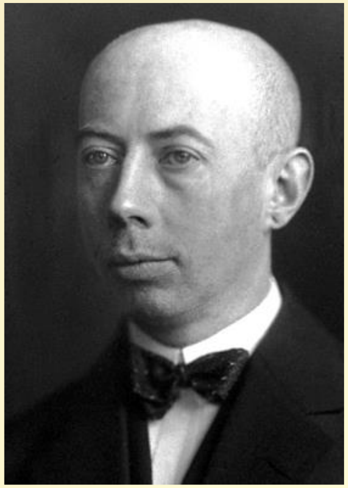
Second Year Lab (PH2103):
(i) Franck-Hertz experiment
(ii) Verification of Stefan-Boltzmann's law

Rumi De
Department of Physical Sciences
IISER Kolkata

Franck-Hertz Experiment

James Franck



Gustav Hertz

Franck-Hertz Experiment (1914)

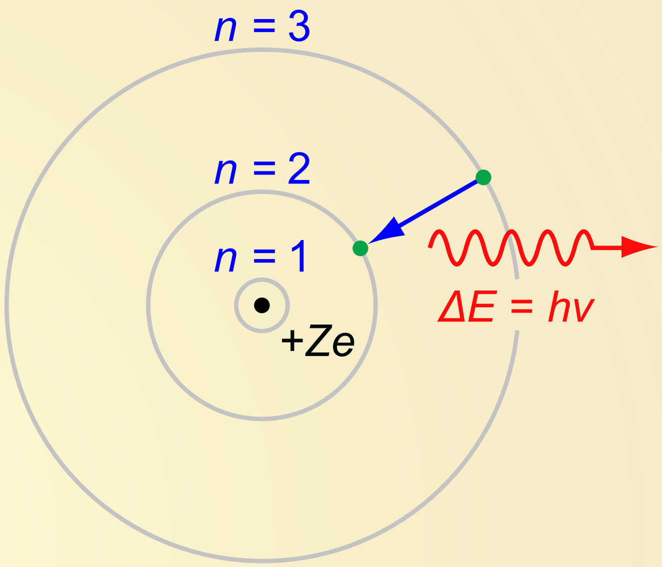
Atoms emit radiations at discrete frequencies, thus, the energy levels of the atoms are quantized.

- German physicists - won the 1925 Nobel Prize for Physics for their "discovery of the laws governing the impact of an electron upon an atom"

(References: Concepts of modern physics by Arthur Beiser, Wikipedia, Google)

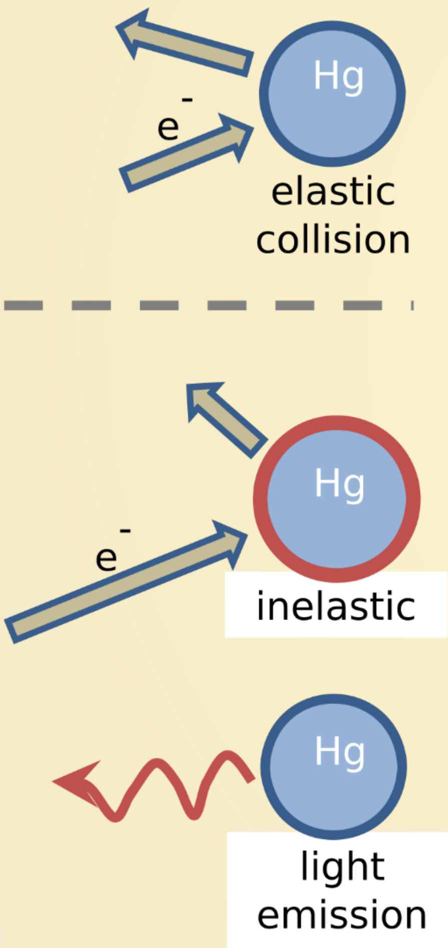
Bohr Model

- Niels Bohr – proposed atomic model (1913)
- Electrons revolve in certain stable/ stationary orbits around the nucleus without radiating any energy
- The stationary orbits are attained at distances for which the angular momentum of the revolving electron is an integer multiple of the reduced Planck constant: $\mathrm{mvr} = n\hbar$
- Electrons can only gain and lose energy by jumping from one allowed orbit to another, absorbing or emitting electromagnetic radiation with a frequency: $\Delta E = h\nu$
- Bohr's atomic model predicted the emission lines of the Hydrogen atom

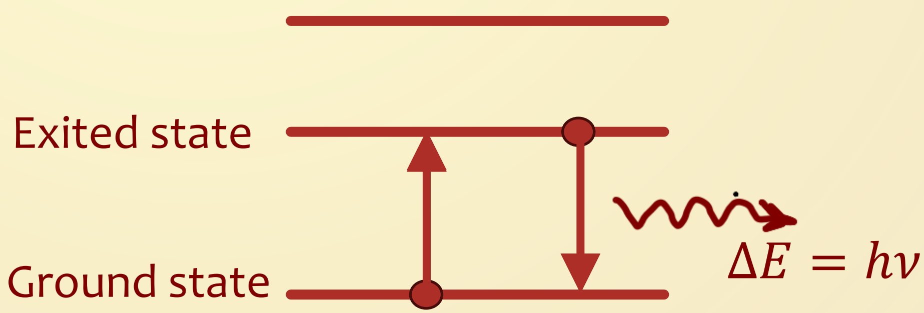


Franck-Hertz Experiment

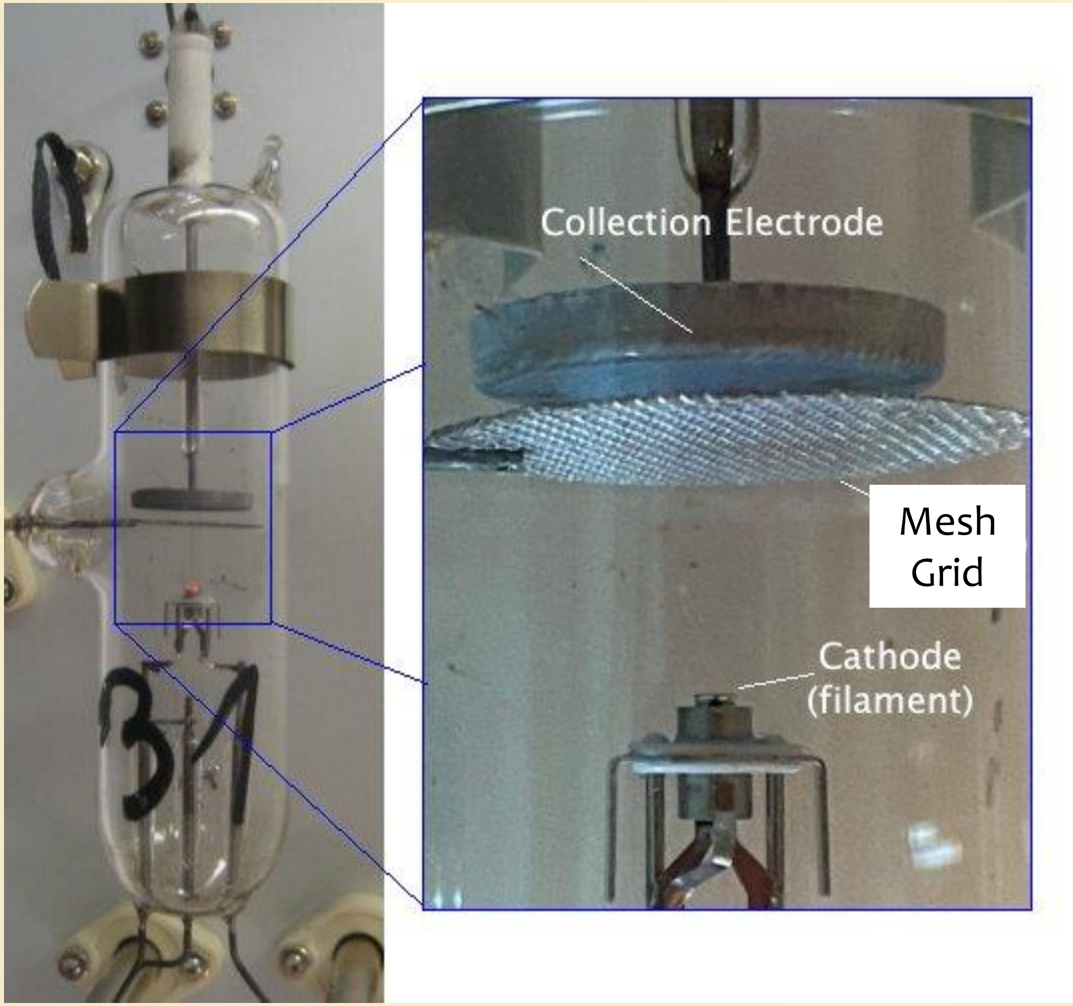
Atomic Exitation:



- It is possible to excite an atom through the collision mechanism - **inelastic collision with low energy electrons**
- Elastic collision: electrons do not change their speed but change their direction
- Higher energy electrons undergo inelastic collision and loose their energy. The energy is transferred to the atoms, and they get excited. The excited atoms subsequently emits light and returns to its original state

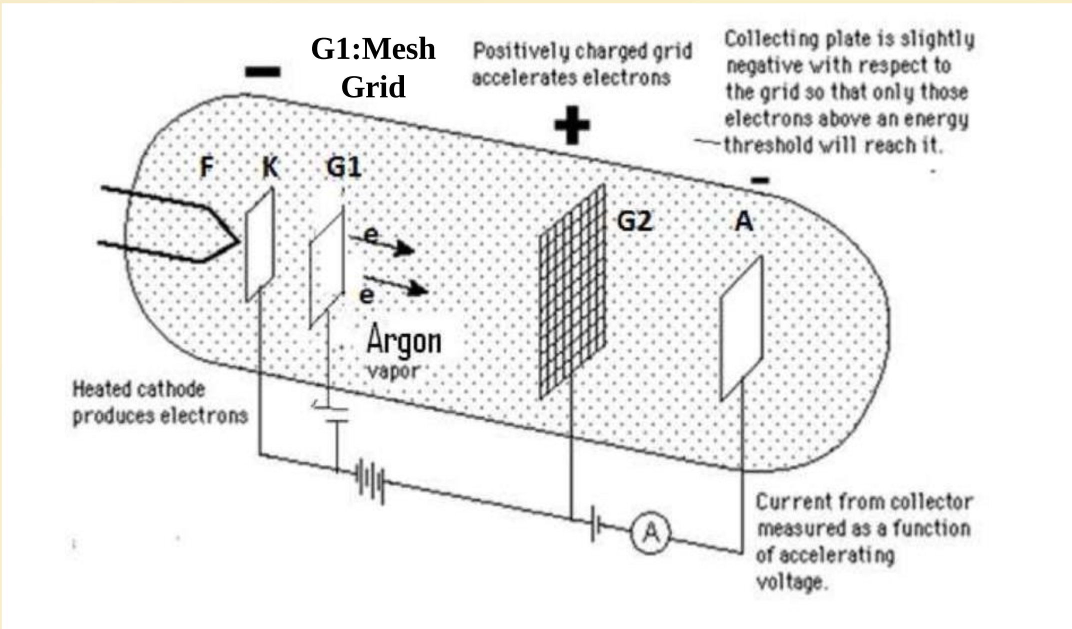


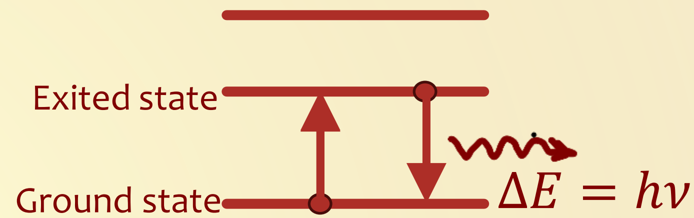
Franck-Hertz experimental set up

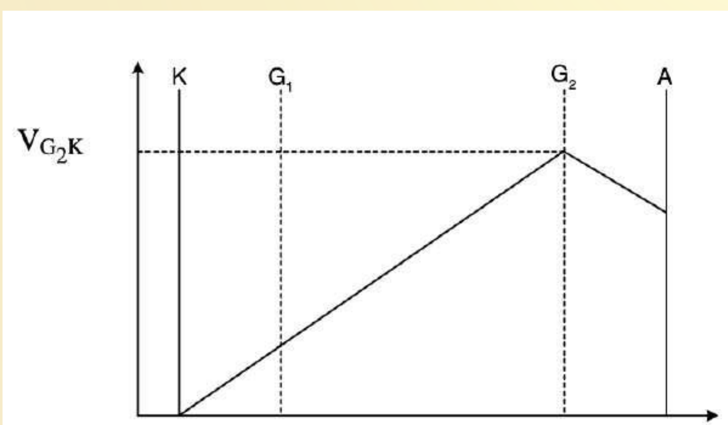


Photograph of a vacuum tube used for the Franck–Hertz experiment. There is a droplet of mercury inside the tube, although it is not visible in the photograph. C – cathode assembly; the cathode itself is hot, and glows orange. It emits electrons which pass through the metal mesh grid (G) and are collected as an electric current by the anode (A).

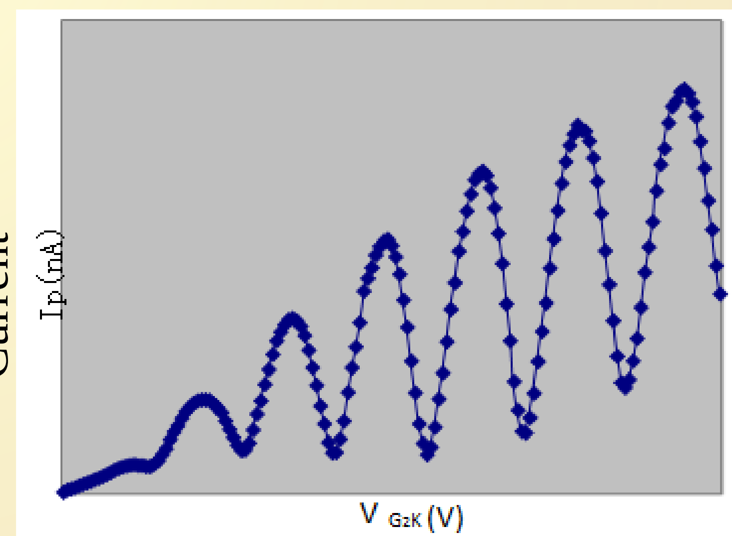
Franck-Hertz experiment: our lab set up







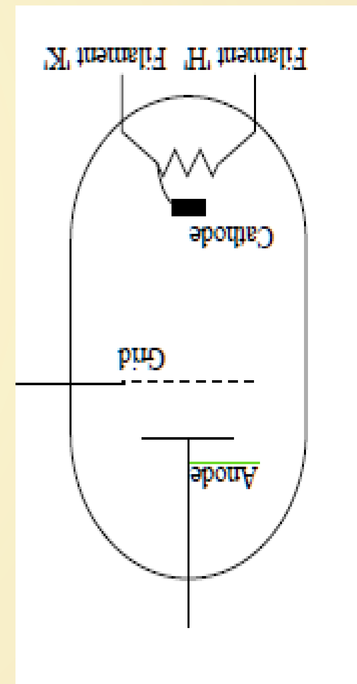
Current



Accelerating Voltage G2

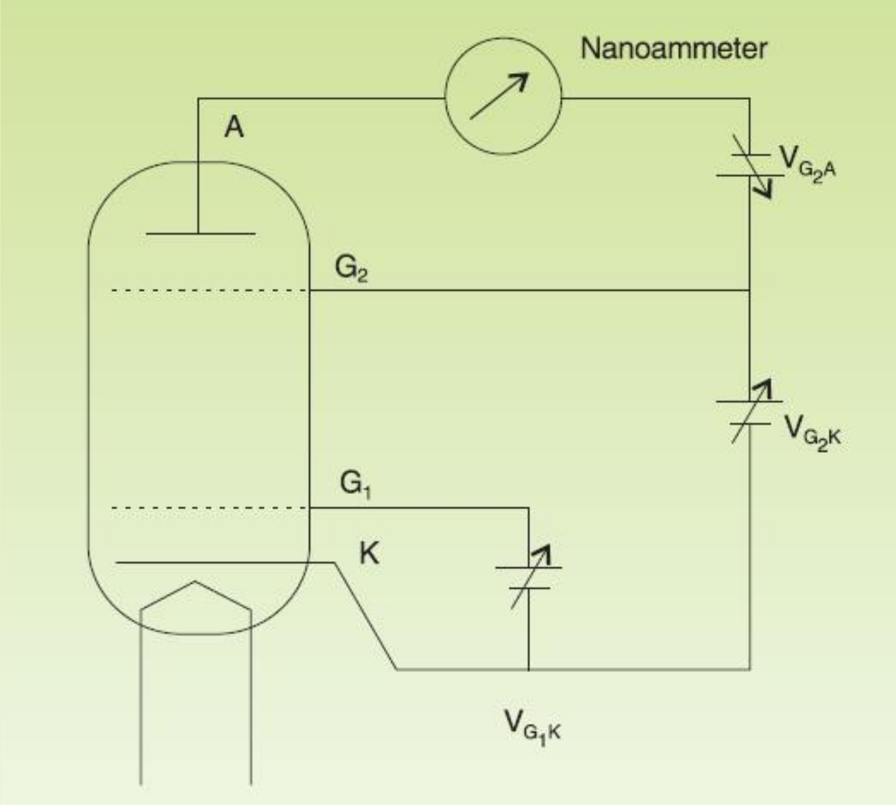
Franck-Hertz experiment using Neon gas

Glowing emission with increasing accelerating potential



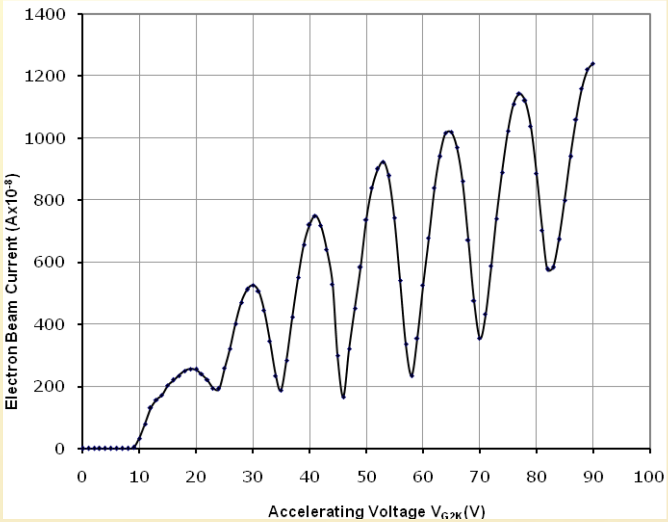
(Source: Wikipedia)

Franck-Hertz experiment using Argon

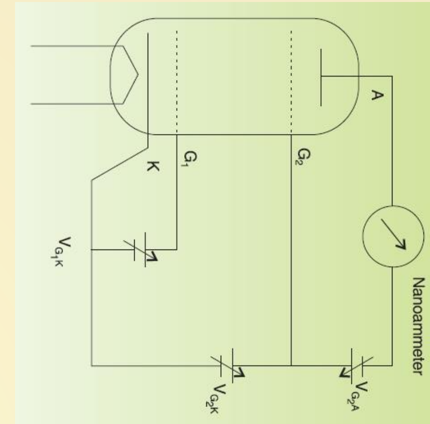


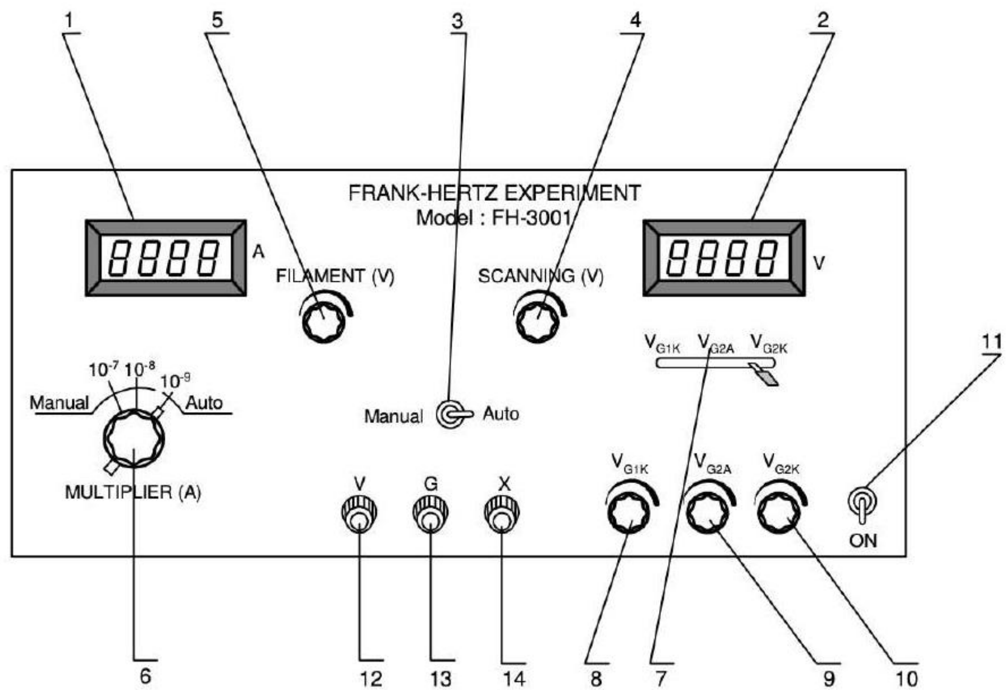
Argon First exited state:
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5\ 4s^1$.

corresponding to ~ 11.83 eV



Franck-Hertz experiment: our lab set up





1) Ammeter
2) Voltmeter
3) Manual - Auto Switch
4) Scanning Voltage Knob
5) Filament Voltage Knob
6) Current Multiplier Knob
7) Voltage Display Selector: V_{G_1K}, V_{G_2A} or V_{G_2K}
8) V_{G_1K} Adjust knob : 1.3 - 5V
9) V_{G_2A} Adjust Knob : 1.3 - 15 V
10) V_{G_2K} Adjust knob : 2.0 - 90V
11) Power Switch
12) Y-Output Terminal
13) Ground Terminal
14) X-output Terminal

Stefan-Boltzmann's Law of Radiation

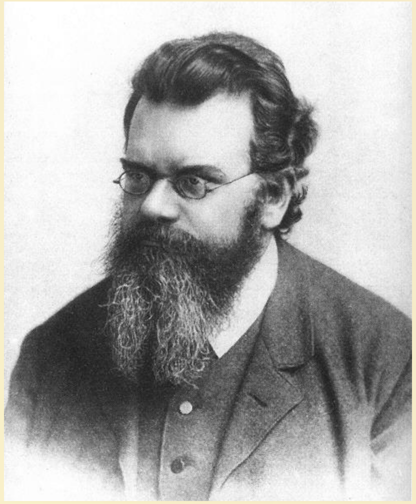
Verification of Stefan-Boltzmann's law

➢ Stefan-Boltzmann law:

The total energy emitted by a black body per unit area and unit time is proportional to the fourth power of the body's absolute temperature

- Josef Stefan empirically (experimental observation) derived the relationship (1877), Ludwig Boltzmann, his doctoral student, derived the law theoretically (1884)

Josef Stefan



Ludwig Boltzmann

Austrian physicists

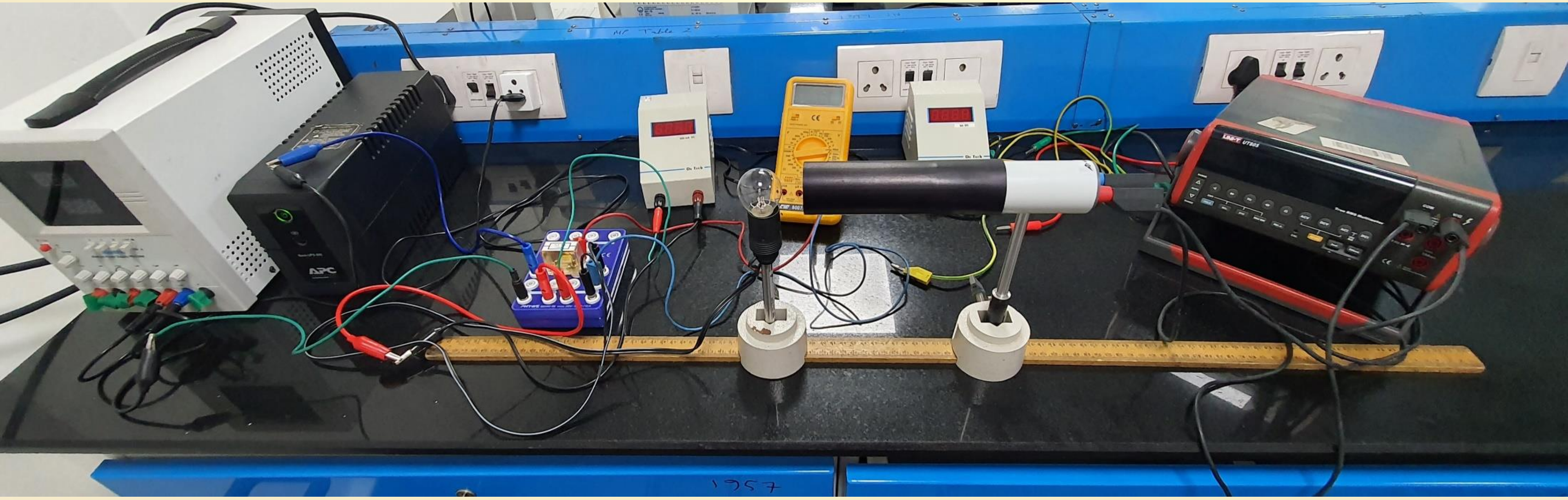
$$L(T) = \sigma T^4;$$ σ : Stefan–Boltzmann constant.

- In general, $L(T) = \varepsilon \sigma T^4; \quad 0 \leq \varepsilon \leq 1$

ε is the emissivity of the surface emitting the radiation. An emissivity of one corresponds to a black body.

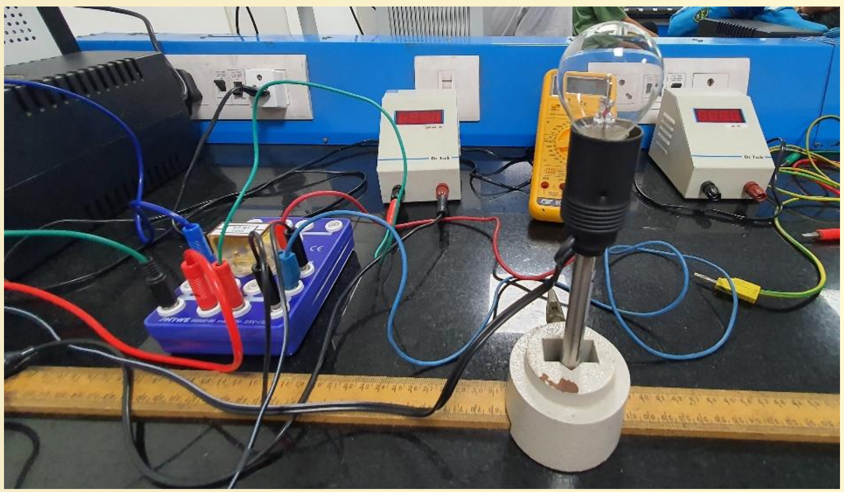
Experimental set up

- Stefan-Boltzmann law is also valid for **‘grey body’**
- A grey body has a surface with a wavelength independent absorption coefficient of less than one.
- In this experiment the filament of an **incandescent lamp** is taken as a model for a grey body and its emission is investigated as a function of its temperature



Measurement of temperature of the filament (grey body)

- **Absolute temperature, T= t + 273, of the filament is calculated from the measured resistance of the tungsten filament**



$$R(t) = R_0\,(1 + \alpha t + \beta t^2)$$

with R_0 = resistance at 0 °C

α = $4.82 \cdot 10^{-3}\ \mathrm{K}^{-1}$

β = $6.76 \cdot 10^{-7}\ \mathrm{K}^{-2}$

$$T = 273 + \frac{1}{2\beta}\left[\sqrt{\alpha^2 + 4\beta\left(\frac{R(t)}{R_0} - 1\right)} - \alpha\right]$$

Measurement of the resistance of the filament

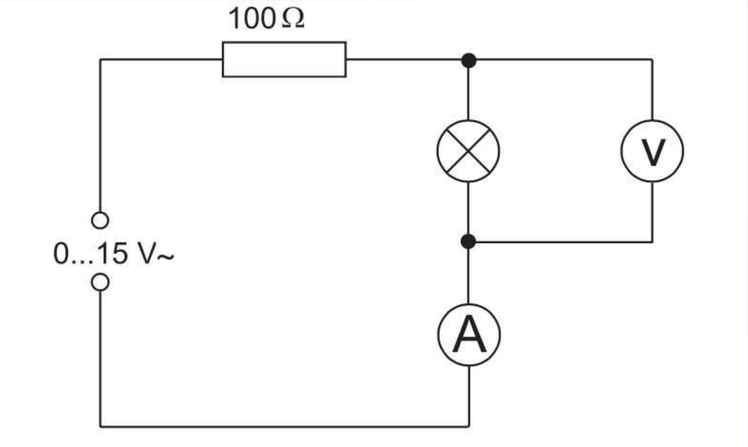
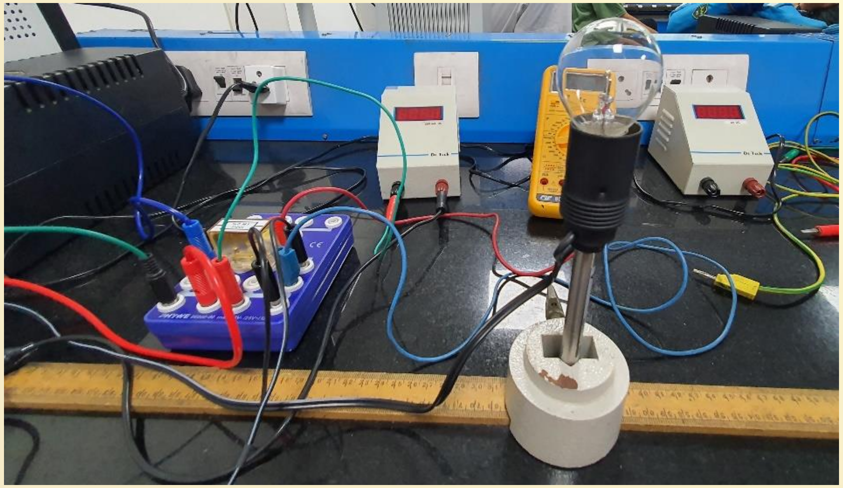


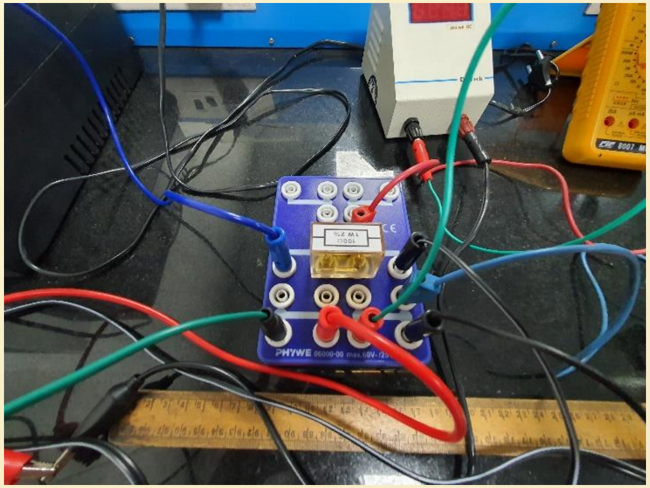
Fig. 3: Circuit for measuring the resistance of the lamp at room temperature.

- Filament's resistance is measured at room temperature using Ohm's law, e.g. by current and voltage measurements across the filament
- Current should be low enough (in mA range) not to heat the filament; therefore, 100 Ohm resistor is used

$$R(t) = R_0\,(1 + \alpha t + \beta t^2)$$

with R_0 = resistance at 0 °C





Measurement of the resistance of the filament higher than the room temperature

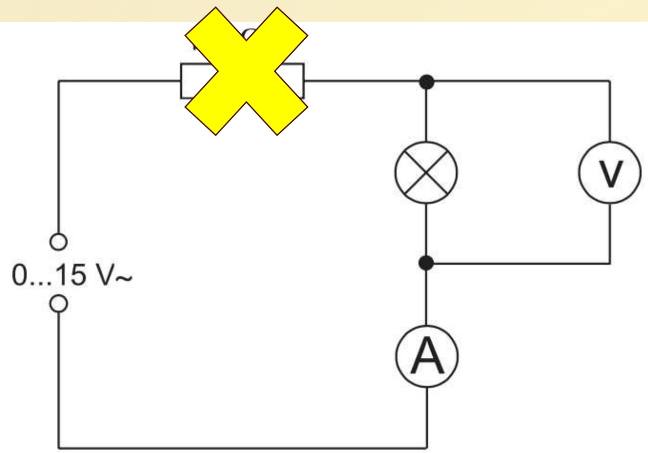


Fig. 3: Circuit for measuring the resistance of the lamp at room temperature.

$$R(t) = R_0\,(1 + \alpha t + \beta t^2)$$

with R_0 = resistance at 0 °C

$\alpha = 4.82 \cdot 10^{-3}\ \mathrm{K}^{-1}$

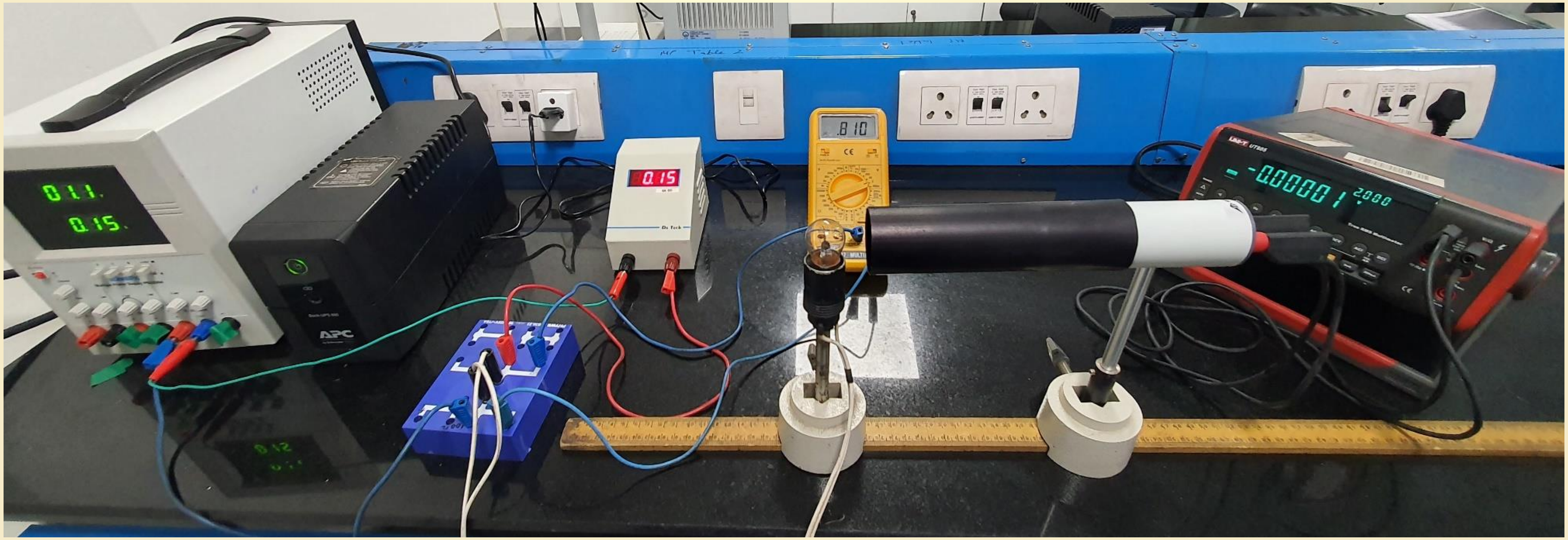
$\beta = 6.76 \cdot 10^{-7}\ \mathrm{K}^{-2}$

- The current through the filament is increased in steps
- The resistance (R) of the filament is measured at certain temperature by measuring current (Amp) and voltage across the filament.
- The circuit for measuring the resistance of the filament remain the same, however, 100 Ohm resistance is removed to increase the current (Amp) through the filament.
- From the measured resistance, corresponding temperature (T) of the filament is calculated

$$T = 273 + \frac{1}{2\beta}\left[\sqrt{\alpha^2 + 4\beta\left(\frac{R(t)}{R_0} - 1\right)} - \alpha\right]$$

Measurement of energy flux of the filament

- **Energy flux is measured using a thermopile** that is aligned to with the filament lamp to receive the radiation.
- The current through the filament is increased in steps and the corresponding temperature (T) of the filament and thermoelectric e.m.f. of the thermopile is measured. **Temperature is measured from the resistance of the filament.**



Measurement of energy flux of the filament

- For a fixed distance between filament and thermopile, the energy flux, Φ, which hits the thermopile is proportional to L(T):

$$\Phi \sim \mathrm{L} \sim T^4$$

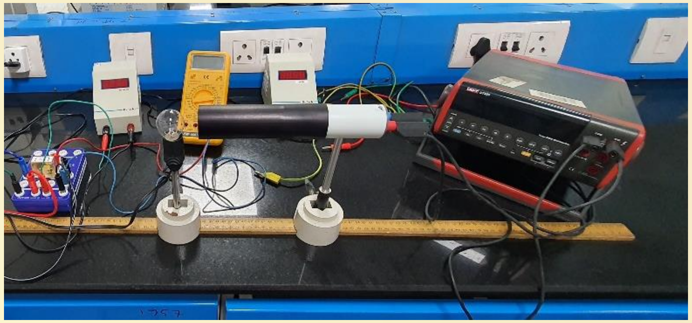
- As the flux, Φ, is proportional to the thermo-electric e.m.f., U_{therm}, of the thermopile,

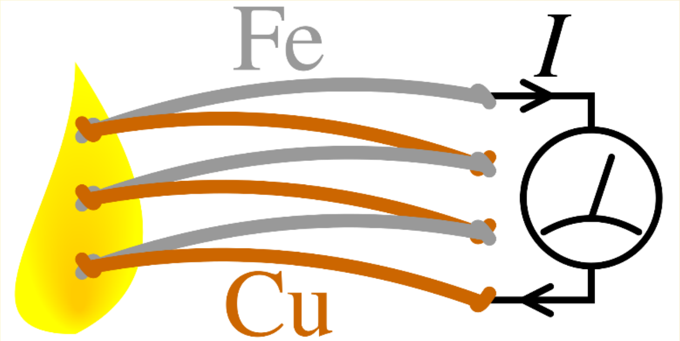
$$\Phi \sim U_{\text{therm}}$$

- Thus, $U_{\text{therm}} \sim T^4$;

$$\ln(U_{\text{therm}}) = 4\ \ln T\ + Const$$

- **We can find the slope from the data fitted to a straight line** (plot $\ln(U_{\text{therm}})$ Vs $\ln T$ **or plot in log scale)**



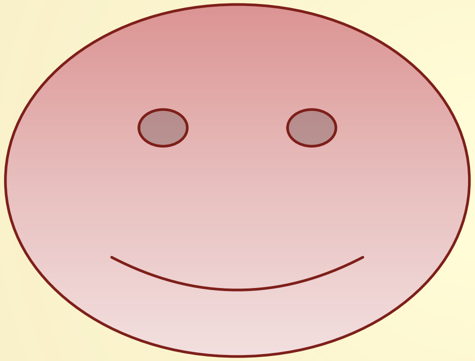


Seebeck effect in a thermopile made from iron and copper wires

Note: thermopile is also radiate at room temperature following T^4 law, However, we neglect the contribution in our experiment

To do list in the experiments

- **Franck-Hertz** (determination of the first excited state of Argon)
  - At least three sets of readings by varying the voltages V_{G1K} and V_{G2A}
- **Stefan-Boltzmann** (verification of the Stefan Boltzmann Law)
  - To calculate the room temperature resistance of the filament, take 6-7 current values (in mA range) to p lot V vs I curve.
  - At least 6-7 readings in filament lamp glowing condition
  - find the slope from data fitted to a straight line



Enjoy