Determination of the $\frac{e}{k}$ ratio with a bipolar transistor

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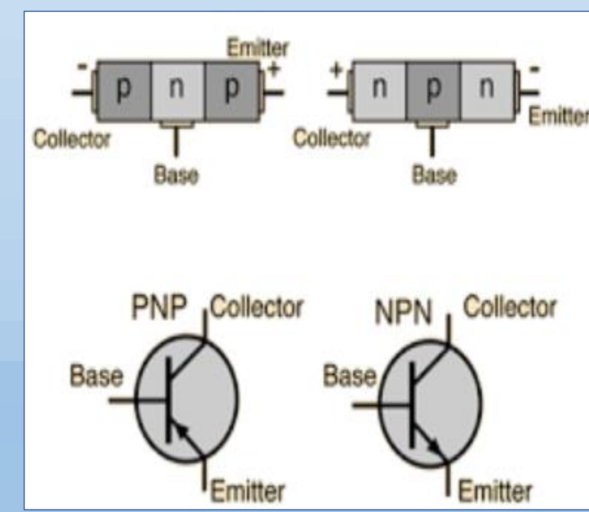
Abstract

The $\frac{e}{k}$ ratio has been determined from I_c vs U_{EB} characteristics of a bipolar transistor (2N3055, n-p-n type), collected at several temperatures between 304 and 365K. The obtained value of the $\frac{e}{k}$ ratio is equal to $11417 \pm 17 \frac{K}{V}$ and is not in agreement with the accepted value of $11604 \frac{K}{V}$.



Theoretical concepts

Electrical conductors are materials in which some of the electrons are free electrons that are not bound to atoms and can move relatively freely through the material, whereas electrical insulators are materials in which all electrons are bound to atoms and cannot move freely through the material. Semiconductors are class of materials in which charge-carrier densities are intermediate between those of insulators and those of conductors.

An intrinsic semiconductor, such as germanium or silicon, have four outer electrons available for bonding. Figure 1 suggests that there are no free electrons to conduct electric current. This is strictly true only at the absolute zero temperature, however , the conductivity of semiconductors increases rapidly with temperature. At any other temperature, thermal energy will cause a small fraction of the covalent electrons to be excited into conduction band and become conduction electrons and thus be able to conduct electrical current. When an electron is excited and becomes free, it leaves behind a hole in the valence band. The holes are mobile particles carrying positive charge at ambient temperature. A much larger number of electric curriers can be introduced if desired by introducing suitable impurity atoms.

The impurities doped into the semiconductor can be either of p-type, when atoms with three electrons in the outer shell are added creating positive holes, or of n-type, when atoms with five electrons in the outer shell are joined to establish a zone with free electrons.

Figure 2 shows a p-n juncton. It is a structure formed by neighboring regions with differently doped, p-type and n-type zones. The p-n junction conducts electric current in only one direction thus the p-n junction, called also a semiconductor diode, is an electric rectifier.

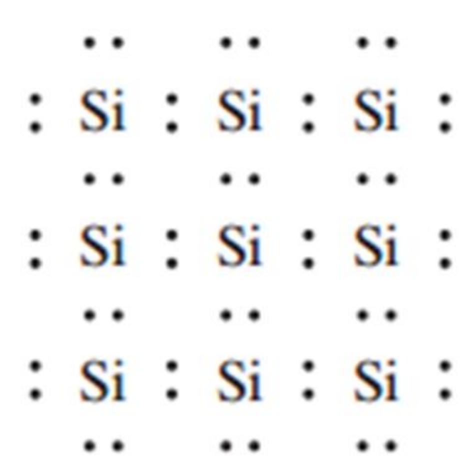


Figure 1. The silicon crystal estructre in a two dimensional representation

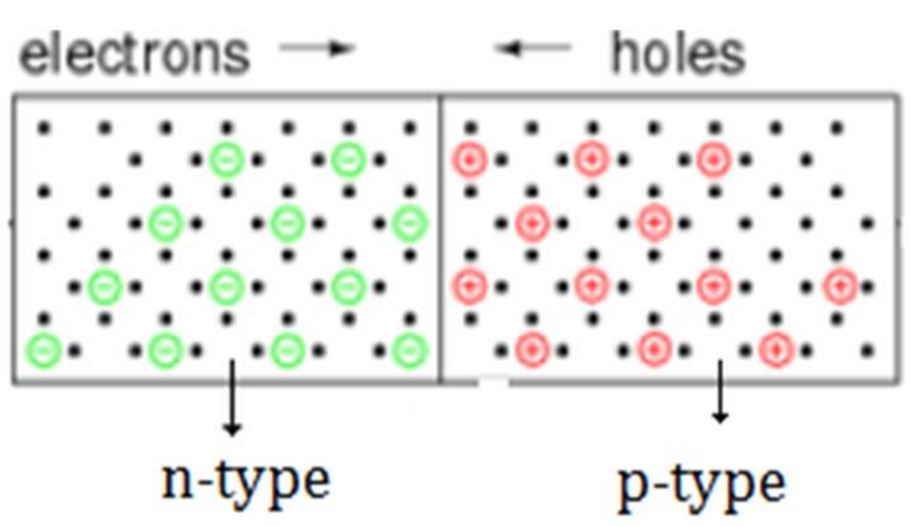


Figure 2. Electrons flowing from n-type zone to p-type zone znd positives holes flowing from p-type zone to n-type zone

A bipolar transistor is created with two p-n junctions. It consists of a emitter and a collector at the ends, and a base between them. The small base current controls the collector current.

The bipolar transistor satisfies the equation $I_c = I_0 \cdot exp\left(\frac{eU_{EB}}{\mathrm{mk}T}\right)$ with $m \approx 1$, where I_c is the collector current, U_{EB} is the difference of potential between the emitter and the base and T is the temperature.

Experimental part

A Digital Multimeter-Keithley 2100 and a digital Voltimeter type V540 were used to collect I_c vs U_{EB} characteristics at several selected temperatures between 304 and 365 K. The electric circuit is showed in Fig. 3.

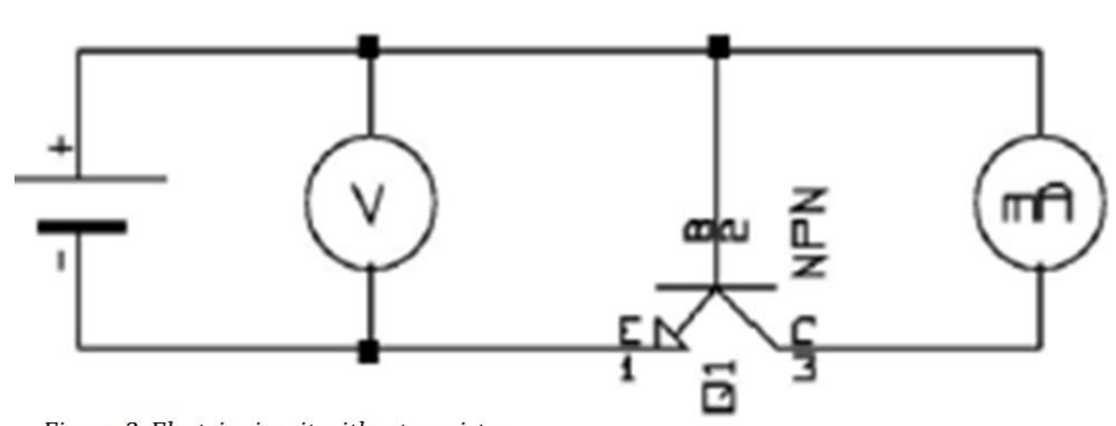


Figure 3. Electric circuit with a transistor

Results

Fig.4 shows a set of isothermal $Ln(I_c)$ vs U_{EB} dependences fitted with linear regression. Assuming m=1, the slope of particular line is equal to $\frac{e}{\mathrm{kT}}$. Thus the $\frac{e}{k}$ ratio can be determined from the slope vs. 1/T dependence as shown in Fig.4.

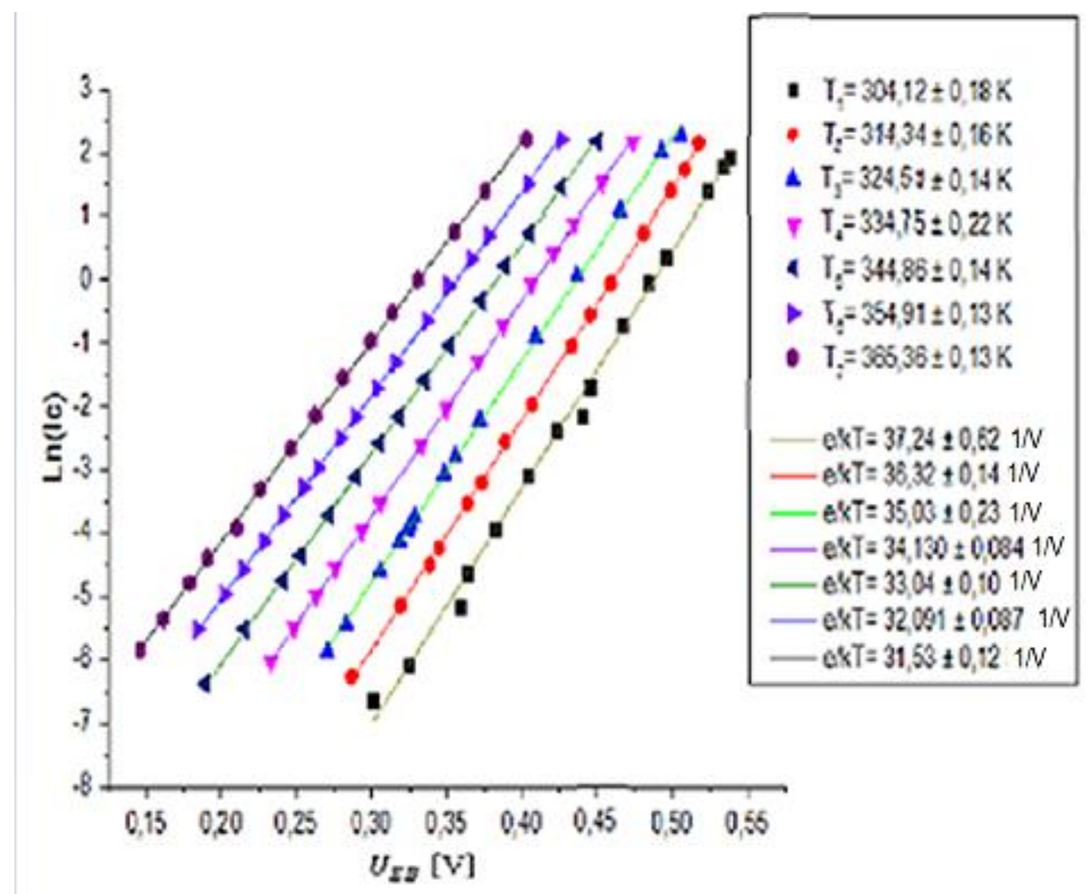


Figure 4. Natural logarithm of the collector current versus the differece of potential between the emitter and the base.

$$I_c = I_0 \cdot exp\left(\frac{eU_{EB}}{\mathrm{k}T}\right)$$

$$Ln(I_c) = \frac{e}{\mathrm{kT}} U_{EB} + Ln(I_0)$$

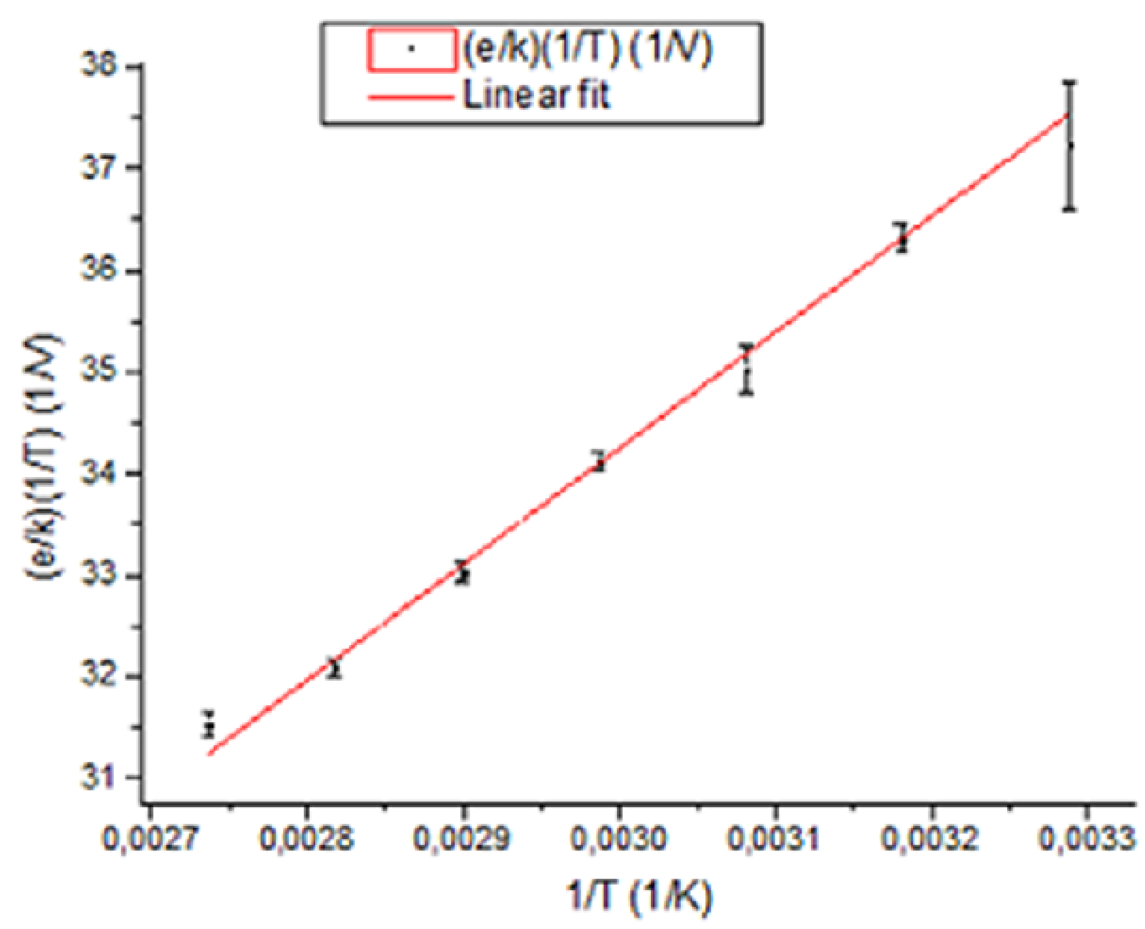


Figure 5. PLot of e/kT vs 1/T.

$\frac{e}{k}$ = 11417 ± 17 K/V

The determined $\frac{e}{k}$ [1]ratio is equal to 11417 ± 17 K/V and is not with agreement with the accepted value equal to 11604 $\frac{K}{V}$. The discrepancy is due to systematic errors. The first source of systematic errors is the assumption of m=1 which is valid only for an ideal transistor. For a real one a deviation of few % from m=1 is usually observed. The second source of systematic errors is the fact that the temperature was measured at the heat sink of the transistor. The real temperature of the p-n junctions forming a transistor could slightly differ from the heat sink temperature.

References

[1] John W.Jewett, Raymond A. Serway, “Physics for Scientists and Engineers,” Broks Cole, Boston, 9th Ed., pp. 2, 579