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An Experiment to Confirm the Validity of Statistical Physics Result of "CONONICAL ENSEMBLE"

Vishal Shukla[1], Rahul Tripathi[2], Sanjeev Kumar Trivedi[3]
[1]Department Of Physics , Lucknow University ,Lucknow-226001
[2, 3]Mumtaz P.G College, Lucknow University ,Lucknow-226020

Abstract: Description and Confirmation of validity of Statistical Physics result "Canonical Ensemble" i.e. canonical distribution by measuring the collector current in a transistor as the base- emitter voltage is varied with different temperature also, The Experiment gives a very convincing demonstration of the canonical distribution and ensemble, in which the probability of occupancy of a state of energy E is proportional to $e^{-E/kT}$ ***with the use of NPN- Power transistor.***

Keywords***: NPN-Power Transistor, breadboard, multi-meter, resistance (100Ω), Icebox, thermometer, canonical ensemble.***

I. INTRODUCTION

Perhaps the single most important and useful result in statistical mechanics is the canonical distribution,[1] in which the probability density P(E) that a system with a fixed number of principles, in equilibrium with a heat bath at temperature T, has energy E is proportional to the

Boltzmann factor e^ weighted by the degeneracy g(E).

$$P(E) \propto g(E)e^{-E/kT} \quad \cdots\cdots(1)$$

Where k is Boltzmann's constant. The result (1) is also called the "Boltzmann distribution" but student often confuse this distribution with the "MAXWELL-Boltzmann distribution"[2]. ,which applies only to an ideal gas .Instead we use the name "Canonical distribution" because it refers to the distribution in the canonical ensemble, and is the terminology used by Gibbs.

In spite of central role of the canonical distribution and its wide range of application, it is not easy to find out simple experimental demonstration suitable for an laboratory .Although there are many chemical application in which T is varied and the result change in chemical concentration are reaction rate is measured, it is difficult to vary the energy E in such experiments and thus to demonstrate Eq. (1) in its full generality. The same applies to physical experiments such as measurements of the density profile of a gas in a centrifuge. The current- voltage characteristic of a vacuum diode depends on the canonical distribution but it's complicated by space charge, electrode geometry, and other confusing effects. This paper describes the simple experiment in which E & T can both be varied, and the validity of the Eq.

(1) confirmed over a range of six or more decade in P(E) . The idea is to measure the collector current in a transistor as the base-emitter voltage is varied. Although such a measurement of a transistor characteristic is a staple of electronic courses, it does not seen to be generally known that one can use such a measurement to demonstrate this fundamental result of statistical mechanics . It follows from Eq.(1) that the probability P(ΔE) of a particle over coming an energy barrier of height ΔE is proportional to

$$\int_0^\infty g(€)e^{-(€+\Delta E)/kT}\, d€,$$

where € is the energy measured from the top of the barrier and g(€) is the density of the state in the barrier region . This relation can be integrated to give

$$P(\Delta E)=f(T)e^{-\Delta E/kT}, \quad \ldots..(2)$$

where f(T) is a relatively slowly varying∝ function which depend upon the form of g(E). In a simple three –dimensional system g(€) $€^{1/2}$∝,so that

$$f(T) \quad T^{3/2}.$$

One example of particles overcoming a barrier by their thermal energy is the motion of the electron in an NPN transistor. A bi-polar transistor consist of two p-n junction back to back , so that the electron move in the potential profile sketched in fig(1). An electron has a certain probability, given by Eq.(2), of occupying a state above the barrier . if it does ,it can cross the barrier and reach the collector, contributing to what is called the "diffusion current" from emitter to collector. The barrier between the collector and the base is sufficiently high that the probability that an electron in the collector returns to the base is negligible. For this reason, A transistor give more satisfactory results then a simple p-n junction diode. If we neglect the very small current flowing in the base connection (which is due to electron-hole recombination in the P-type base region) , the diffusion current from emitter to collector Id is determined by P(ΔE).

The circuit is show schematically in fig (3) The 100Ω resister in series with the power supply protect the transistor from damaged and place no role in the measurement. The barrier height ΔE is varied by controlling the voltage V between the Base and Emitter. At zero voltage the barrier has a certain intrinsic value ϕ, which is close to the band gap of the semiconductor[3] (about 1eV in silicon)[5]. If the voltage is positive on the base (the "forward" direction of the base-emitter diode), it reduces the barrier.

$$\Delta E=\phi-qV \quad ....(3)$$

where –q is the charge on the electron. Because the diffusion current Id is proportional to P(E), which is given by Eq.(2), we have

$$Id=I0e^{qV/k\,T} \quad ....(4)$$

Where,

$$Io\propto f(T)e^{-\phi/kT} \quad .....(5)$$

In addition to the diffusion current, there is a voltage independent reverse current called the "generation recombination" current, which arises from thermal generation of electron-hole pairs in the junction region. It is independent of V and is equal to –I0 exactly canceling the diffusion current at zero voltage, as it must. Hence the total collector current is

$$Ic=Id-I0=I0[e^{qV/KT}-1] \quad ...... (6)$$

Eq.(6) is known as the Ember's-Moll, Equation. In a typical transistor at room temperature, I0<Na, so that the generation combination contribution [the -1] term in Eq. (6) can be neglected, and Eq. (6) can be written as

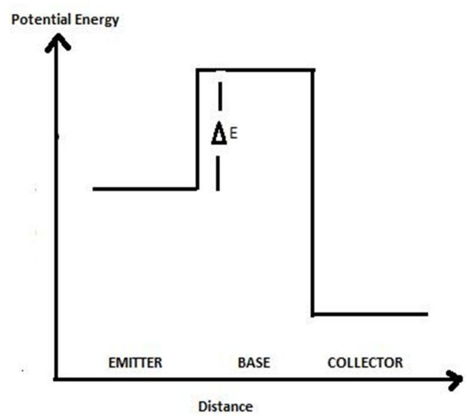

Fig.1. Sketch of the potential energy of an electron, as function of position in a transistor

$$Log10Ic=log10I0+qV/2.3Kt \quad .... (7)$$

At high current there is a significant voltage drop across the series resistance in the transistor contacts, so the voltage across the junction is less that measured. This effect is minimized by using a power transistor with a large junction area we used a 2N3019 silicon transistor, which can handle collector currents up to 10 A. deviations from Eq.(6) are observed only at currents over 100mA.we used a digital voltmeter with a maximum sensitivity of 10-7A, so the Eq.(6) or Eq. (7) can be tested over a range of six decades in IC.

The experiment consists of varying V and measuring IC, with the transistor at different temperatures. we used three temperature a dry ice-propanol bath at 220K,room temperature(300K) ,and the oil bath immersed in boiling water at 375K.expect at the high temperature and lowest voltage ,the generation recombination current is negligible. so that the plot of log10Ic against V are linear ,as shown in fig. the straight line are consistent with fig with

q/k=11600k/eV.

Linear extrapolation to V=0 gives Io. Although the extrapolation is not very reliable, particularly at the lowest temperature, the range of I0 is so large[3] (15 orders of magnitude in the temperature range that we used) that one does not need great precision to obtain a good result

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.fig 4 shows an Arrhenius plot of log10($I0T^{-3/2}$) against 1/T. Data at more temperatures would be needed to pin down the temperature dependence of f(t) accurately but our three data points are consistent with a straight line .

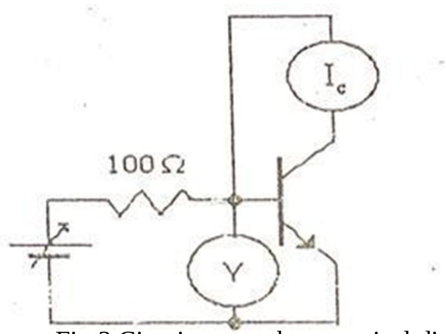

Fig.2 Circuit to test the canonical distribution

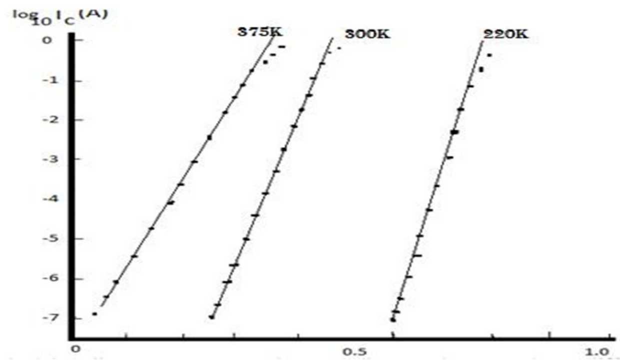

Fig.3 Collector current V/s base-emitter voltage at three different temperatures

As expected if f(T) varies as $T^{3/2}$,the slope of the line in which is larger than the energy gap of the silicon ,but is consistent with the gap extrapolation to 0K,as expected if PHAI varies linearly with T over the range of measurement. There is a question of interpretation which is of pedagogical interest. what do we actually measure when we take the slope of the logic vs. V plot? To answer this question properly, we must first distinguish between macroscopic and microscopic quantities Typical macroscopic quantities which are important in statistical physics are the gas constant R the faraday F (the charge needed to electrolyze one mole of univalent substance), and atomic or molecular 'weight'. Typical "microscopic" quantities are Boltzmann constant k, the charge on the electron q, and the actual mass of an atom. The two classes are related by Avogadro's number NA :[4] For example, R=NAk and F= NAq. In the thermodynamic limit in which NA→∞ and k→0 , macroscopic quantities remain finite while microscopic quantities vanish. Although the former group has been accurately determine by the second half of the 19^{th} century, the latter group where only known in order of magnitude even by the end of the century. In the present experiment we measure the ratio q/k , i.e. F/R. this ratio macroscopic . it would be incorrect to call it a "measurement of the charge on the electron," As has been claimed in a laboratory equipment catalog describing an experiment on a p-n diode which is in principle similar to this one.

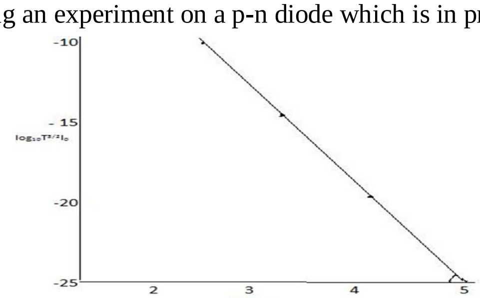

Fig.4 Arrhenius plot of the current extrapolated to zero bias, Io corrected for the $T^{3/2}$ Temperature dependence of the pre-exponential factor in Eq. (5)

II. CONCLUSION

In order to measure q or k separately, we would have to measure some quantity which vanishes in the continuum limit. The Millikan oil drop experiment is one such measurement but so are measurement of shot noise, which give q , or of Johnson noise or Brownian motion , which give k.

III. ACKNOWLEDGEMENT

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REFERENCES

[1] F. Fischer and R. L. Wild, “Demonstration of reduced gas pressure in a centrifugal field”, Am. J. Phys. 47, 450-451 (1979).

[2] B. R. Corson, “Apparatus and methods”, for the precise determination of Boltzmann temperature,” Rev. Sci. Instrum 41,163-175 (1970); A. W. Knudsen, “Boltzmann temperature: An instructional experiment for the advanced laboratory,” Am. J . phys. 53, 409-415 (1985).

[3] For a more complete and accurate treatment, see a text on transistor for example, A. s. grove, Physics and technology of semiconductor devices (Wiley, new York, 1967), Sec. 6.6b and 7.2 .

[4] J. A. Earl, “undergraduate of experiment on thermal and short noise,” AM. J. Phys. 43 575-579 (1966); Y. kraft maker, “Two students experiments on electrical fluctuations,” ibid, 63, 932-935 (1995).

[5] Heywang, W. and Zaininger, K. H. (2004) "Silicon: The Semiconductor Material", p. 36 in Silicon: evolution and future of a technology. P. Siffert and E. F. Krimmel (eds.).

[6] Zhang, Kan; Seo, Jung-Hun; Zhou, Weidong; Ma, Zhenqiang "Fast flexible electronics using transferrable silicon nanomembranes". Journal of Physics D: Applied Physics. 45 (14).

[7] Sun, Dong-Ming; Timmermans, Marina Y.; Tian, Ying; Nasibulin, Albert G.; Kauppinen, Esko I.; Kishimoto, Shigeru; Mizutani, Takashi; Ohno, Yutaka (2011). "Flexible high-performance carbon nanotube integrated circuits". Nature Nanotechnology. 6 (3): 156.