Measuring the Planck Constant with LED's

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We outline here the basic principles used in a simple experiment for determining the value of the Planck constant h. The instruments used are likely available in the physics departments of most institutions.

A light-emitting diode (LED) consists of a semiconducting P-N junction that produces visible light when energized. The phenomenon of light emission can be interpreted in terms of the theory of the energy bands of semiconductors. When a recombination of holes and electrons takes place at a junction, the energy is converted into heat (phonons) or light (photons). The radiation frequency depends on the materials employed in the P-N junction and by varying its composition different colors are obtained.

We send the light from these diodes through a monochromator that records the emitted wavelengths and from these the emission frequency ν of the LED. Furthermore, since the value of the electron excitation energy E_g is related to the applied forward voltage V_F, E_g can be established by measuring V_F. These measurements are sufficient to determine the Planck constant.

To make the measurements, apply an alternating voltage to the P-N junction, exciting the transport of electrons that move from the conduction band of the N side to the valence band of the P side. In this transition the electrons pass from a high to a low energy level in the P side of the junction and emit a photon as shown in Fig. 1.

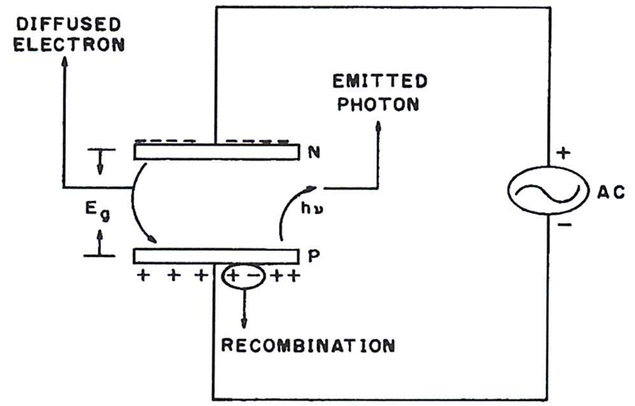

Fig. 1. Inside P-N junction of LED, an electron jumps from the conduction to the valence band. During this process a photon is emitted with energy $h\nu$ corresponding to the band energy gap E_g.

If E_g is the energy gap between the conduction and valence bands, the relation of the energy gap to the frequency of the emitted photon is

$$E_g = h\nu \qquad (1)$$

The wavelength λ of the emitted light as determined by the monochromator is recorded in a register XY, obtaining the relative intensity as a function of the wavelength of the LED as shown in Fig. 2. When the relative in-

Table I. Spectral values and characteristics of LED semiconductors.

LED	V_F(V)	λ (nm)	$\nu \times 10^{14}$ (Hz)	E_g (cV)	Semiconductor
infrared	1.4	900	3.33	1.37	GaAs
red	1.9	678	4.42	1.82	CdSe
light red	1.8	656	4.57	1.88	CdSe
orange	2.0	644	4.65	1.92	GaAsP
yellow-orange	2.1	597	5.02	2.1	GaAsP
yellow	2.0	598	5.01	2.1	GaAsP
green	2.2	574	5.23	2.15	AlAs

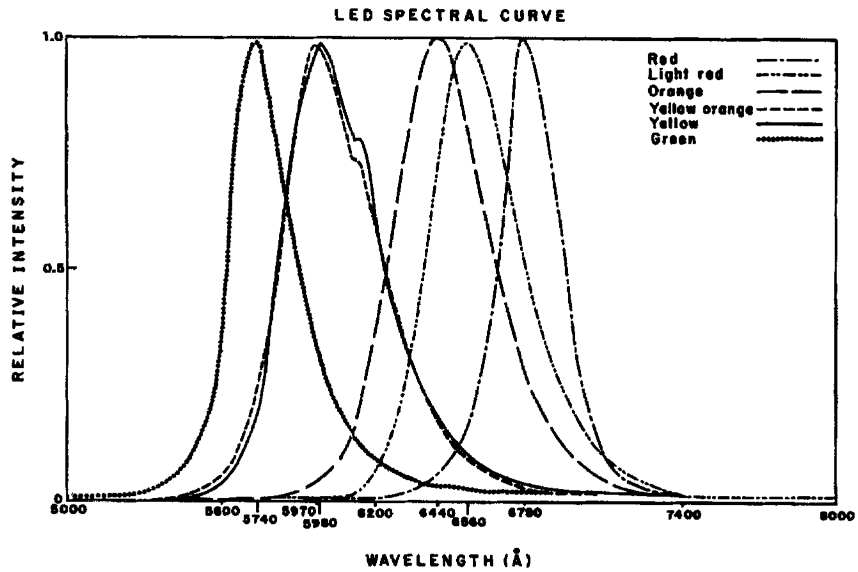

Fig. 2. Curves of recorded LED-emitted photon intensity as a function of photon wavelength.

tensity is maximum, the excitation current flowing through the LED corresponds to the forward voltage V_F. This applied voltage corresponds precisely with the excitation energy of the gap of the LED, which thus emits light with a characteristic wavelength. The forward voltage is related to the energy gap by

$$E_g = eV_F \qquad (2)$$

For an applied voltage, V, higher or lower than V_F, the intensity of the emitted light decreases. Thus the maximum

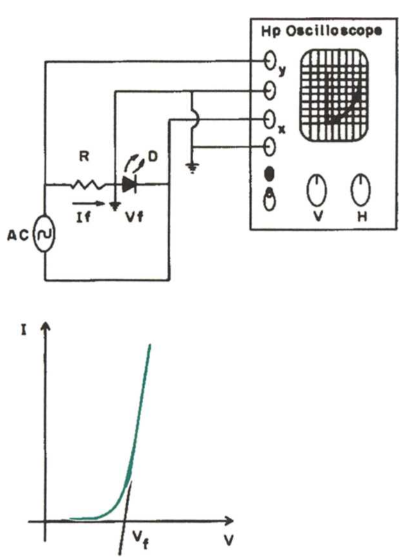

Fig. 3. Scheme of circuit used to determine forward voltage V_F.

intensities, shown in Fig. 2, determine the wavelength λ_{exp}. From Eqs. (1) and (2) we obtain the basic relation

$$V_F = m\nu \qquad (3)$$

where $m = h/c$.

For each color (or frequency), the corresponding forward voltage is determined in the usual way by a plot of the diode current I vs V, which is displayed

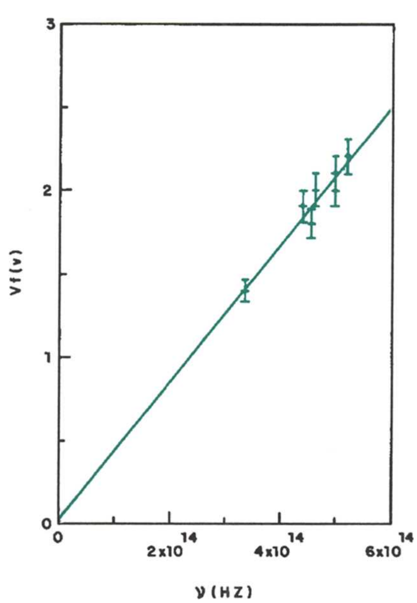

Fig. 4. Graph of forward voltage, V_F, versus recorded photon frequency, ν. The Planck constant is related to the slope of the straight line matching the experimental data.

in the oscilloscope and may be determined using the circuit in Fig. 3. The intersection of the straight line (which extrapolates the plot of Fig. 3) with the V axis determines the forward voltage V_F. The same plot may also be obtained, point by point, using a variable dc source. However, we prefer to use ac because with the circuit of Fig. 3 the plot of the diode current I vs V may be made directly visible on the screen of the oscilloscope.

Relation (3) represents the equation of a line of slope m in a graph where V_F is plotted vs the frequency ν, as shown in Fig. 4. For each measurement the error is shown by the corresponding error bars. The method of linear regression determines the parameters of the straight line, which better covers all the experimental points. After obtaining slope m, the Planck constant is determined from $h = em$. For our setup we obtained the value $m = 4.1 \times 10^{15}$ Js/C with an error of 0.4×10^{-15} Js/C, leading to the value $h = 6.6\ (\pm\ 0.6) \times 10^{-34}$ Js corresponding to a relative error of 10%. This result for h is to be compared with the handbook value 6.626×10^{-34} Js.

Table I shows the characteristics of different LED's.

Acknowledgments

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Suggested Reading

1. L. Sharupih and N. Tugov, *Opto-Electronics* (Nir Publishers, Moscow, 1987), Chap. 1.
2. Pallab Bhattacharya, *Semiconductor Opto-Electronic Devices* (Prentice Hall, Englewood Cliffs, NJ, 1994), Chap. 5.
3. Robert Boylestar and Louis Nashelsky, *Electronic Theory of Circuits* (Prentice Hall, Hispanoamericana, Mexico, 1992), p. 38.