QUESTIONS AND ANSWERS

Contributions to this section, both Questions and Answers, are welcomed. Please submit four copies to the editorial office. Please include a *title* for each submission, include name and address at the end, and put references in the standard format used in the American Journal of Physics. For further suggestions, sample Questions and Answers, and requested form for both Questions and Answers, see Robert H. Romer, "Editorial: 'Questions and Answers,' a new section of the American Journal of Physics," Am. J. Phys. **62** (6) 487–489 (1994).

Questions at any level and on any appropriate AJP topic, including the "quick and curious" question, are encouraged.

Question #53. Measuring Planck's constant by means of an LED

In a rather widespread lab experiment students determine Planck's constant by means of the $I-V$ characteristic (current versus voltage) of a light emitting diode. The experiment can also be found in the catalog of demonstration experiment producers. The method works as follows: A tangent is applied to the sharply rising part of the $I-V$ line of an LED. The intersection of this tangent with the V axis yields a voltage V_D. It is claimed that V_D is the diffusion voltage of the diode. The diffusion voltage is nearly equal to the bandgap energy divided by the electron charge e. Thus Planck's constant can be determined according to

$$h=\frac{eV_D}{f},$$

where f is the frequency of the emitted light and e the charge of the electron.

We don't understand why the above-mentioned intersection should be the diffusion voltage. The equation of the $I-V$ characteristic is

$$I(V)=I_0\left(\exp\frac{V}{V_t}-1\right),$$

where I_0 depends on the diffusion length of the minority carriers, the diffusion constant and the density of the minority carriers, and V_t stands for kT/e. The only characteristic voltage contained in the equation is V_t, which, of course, is not the diffusion voltage.

Moreover, if the intersection of a tangent at the $I-V$ characteristic with the V axis is calculated, any positive value can be obtained, according to which point on the curve is chosen for the tangent.

The strange thing is that Planck's constant comes out rather correctly. We did not find a reference where the procedure is explained convincingly. Can anybody help us?

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Question #54. Chapter summaries: Blessing or curse?

Increasingly, textbooks close a chapter with a summary section: statements of principles (in one sentence each) and displays of major equations. Is there evidence that this practice increases learning? (If so, what kind of evidence?) Or is the practice pernicious? Already too many students skip the reading and try to solve the problems by looking for appropriate equations. Or has the practice merely become firmly embedded in publishers' minds (and perhaps in faculty minds) and hence has become *de rigueur* for authors?

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Answer to Question #29 ["Why is the Coulomb force neglected in e^+e^- pair production?," Kaoru Sasabe, Am. J. Phys. 63(10), 875 (1995)]

As I understand the question, Sasabe asks whether the usually stated minimum photon energy for pair production, $h\nu=2mc^2=1.02$ MeV (where m is the electron rest mass), is an exact result, or whether, instead, the threshold energy for pair production is actually larger[1] than $2mc^2$ by an amount equal to the binding energy of the just-created e^+e^- pair (a quantity which is perhaps infinite if the electron and positron are initially at the same point).

One can invoke uncertainty-principle arguments (always to be regarded with skepticism,[2] especially if quantitative results are to be derived) to argue that it makes no sense to think of the electron and positron as located at the *same* point in space; localization to within a Compton wavelength, $\lambda_c=h/mc$, is about the best one can do. At this distance, $e^2/r=(\alpha/4\pi)2mc^2$, where $\alpha=1/137$ is the fine structure constant. Thus one might anticipate a correction of about one part in 1700 to the threshold energy.

But the "electron-positron binding energy" is actually irrelevant, and Sasabe's question has a much simpler answer. Suppose for the moment that momentum conservation is not a problem. (More about momentum conservation below.) Consider an *initial* state with nothing but a photon: $E_i=h\nu$. And now consider a *final* state, much later, in which we have only an electron and a positron, separated by a very large distance: $E_f=2mc^2+T^++T^-$, with T^+ and T^- the positron and electron kinetic energies. The pair production process is energetically possible if $h\nu\geqslant 2mc^2$. No approximation is involved. The Coulomb force between electron and positron has not been "neglected;" it simply does not enter at all into calculation of the threshold energy.[3]

But let me return to the issue of momentum conservation. Although in QED we think of virtual pairs constantly being produced and then annihilated, decay of a photon in empty space into an electron–positron pair would violate momentum conservation; something else, usually a nucleus of mass M, is needed to take up at least some of the momentum. Near threshold, where $h\nu\simeq 2mc^2$ and the electron and positron velocities are small, the nucleus will recoil with momentum $p\simeq h\nu/c$ and energy $p^2/2M\simeq(m/M)2mc^2$. Thus the incident energy must indeed be slightly greater than $2mc^2$, but