

LETTERS TO THE EDITOR

Prompt publication of brief reports of important discoveries in physics may be secured by addressing them to this department. Closing dates for this department are, for the first issue of the month, the twentieth of the preceding month; for the second issue, the fifth of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.

The Raman Spectra of Three Amines

During the study of the Raman spectra of a series of chain compounds, the spectra of *n*-butylamine, *n*-heptylamine, and secondary butylamine have been determined. The frequencies and relative intensities are given in Table I.

TABLE I.

<i>n</i> -butylamine	330(0), 338(1), 399(4), 440(1), 472(0), 495(0), 794(1), 813(1), 842(1), 872(1), 896(2), 935(1), 962(1), 1030(2), 1050(3), 1083(3), 1123(1), 1184(0), 1301(4), 1442(7), 1459(4), 1476(0), 2727(0), 2873(10), 2906(7), 2930(7), 2960(2), 3317(1), 3383(0).
<i>n</i> -heptylamine	274(3), 822(0), 838(0), 865(0), 894(1), 1066(3), 1120(1), 1164(0), 1296(5), 1433(7), 1454(3), 2719(0), 2847(10), 2890(5), 2925(3), 2951(0), 3315(0).
secondary butylamine	479(3), 765(5), 805(5), 917(3), 996(3), 1048(3), 1130(1), 1160(1), 1263(0), 1299(0), 1344(1), 1376(1), 1439(7), 2727(0), 2871(10), 2924(7), 2961(5), 3321(1), 3364(0).

It seems strange that *n*-butylamine has not previously been studied but the author has not been able to find any reference to such work. The Raman spectrum of this substance is remarkable for the absence of continuous background, and for the large number of frequencies which appear for such a low member of the series. It has been impossible, so far, to obtain the spectrum of *n*-heptylamine as free from background as that of *n*-butylamine. There are dark regions on the heptylamine plates which indicate that if the continuous background could be removed the spectrum would be almost identical with that of *n*-butylamine.

On the Recombination of Electrons and Positrons

The discovery of the positron has opened the possibility of a physical interpretation of the negative energy levels in Dirac's relativistic theory of the electron. In particular the formation of a positron-electron pair under a hard γ -radiation, as observed by Anderson, has been interpreted by Oppenheimer and Plesset¹ as a kind of photoelectric effect, whereby the energy of the absorbed γ -quantum raises an electron from a negative energy state to a positive one, forming a hole or positron and an electron. The reverse process, recombination of a positron and an electron under emission of γ -radiation, has been suggested by Blackett and Occhialini² as a possible explanation of the

radiation observed by Gray and Tarrant³ in the scattering of hard γ -rays. According to these authors, the scattered radiation contains besides the normal Compton scattering, two fairly monochromatic components with energies of about 0.5 and 1×10^6 volts, i.e., very nearly mc^2 and $2mc^2$. The intensity of the hard component is smaller than that

The weak line at about 2725 cm^{-1} seems never to have been reported before for any amine. As was found by Wood and Collins¹ for the alcohols, the 1450 cm^{-1} line seems to have a structure in the case of the amines. A fairly intense exposure with freedom from background seems necessary to show the nature of this line.

A preliminary plate of the spectrum of furane gives the following frequencies: 597, 647, 723, 840, 870, 989, 1034, 1055, 1139, 1380, 1488, 3158. The spectrum of furane is needed to complete the study of the three similar substances, furane, thiophene, and pyrrol.

The Wood-Pfund arrangement of filters was used,—sodium nitrite solution, and praseodymium and ammonium nitrate solution, placed in tubes parallel to the mercury arc. A dispersion of about 20A per mm at 4358A was obtained by the spectrograph. Without the praseodymium filter many lines could not have been distinguished from the background. The sodium nitrate solution was of such a concentration that only the merest trace of the 4046A line was visible on the plates. Thus only those Raman lines due to the 4358A group could possibly be present.

The author is indebted to the Eastman Kodak Company for the privilege of spending a summer in their research laboratories during which time all the preliminary work on these compounds was carried out.

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¹ Wood and Collins, Phys. Rev. **42**, 386–392 (1932).

¹ Oppenheimer and Plesset, Phys. Rev. **44**, 53 (1933). See also Beck, Zeits. f. Physik **83**, 498 (1933).

² Blackett and Occhialini, Proc. Roy. Soc. **A139**, 699 (1933).

³ Gray and Tarrant, Proc. Roy. Soc. **A136**, 662 (1932).

of the soft component, increases somewhat with the atomic number Z , and is for lead 1/3 of the total radiation. The recombination energy of an electron and a positron, both with negligible kinetic energies, is the sum of the rest masses or $2mc^2 \cong 10^6$ volts. Because of the necessary conservation of energy and momentum this energy, in the case that both particles are free, can only be emitted in the form of two quanta of the same energy ($=0.5 \times 10^6$ volt). This type of radiation would therefore explain the soft component. For the hard component the energy must be emitted in one quantum, which is only possible for a strongly bound electron, where the nucleus can take up the recoil momentum of the quantum.

According to this explanation the mechanism of the scattering would be as follows. First the primary γ -quantum is absorbed forming a pair. The high velocity positron which is formed loses its kinetic energy by collisions, and at the end of its path there is a chance of its being destroyed by either of the two processes mentioned above. The ratio of the intensities of the two components should be equal to the ratio of the probabilities of the two processes. Now it has been shown by several authors that the rate of destruction of a low velocity positron by the two quanta process is:

$$R_2 = N\pi e^4/m^2c^3 = 7.5 \times 10^{-16}N, \quad (1)$$

where N is the electron density. The nuclear repulsion prevents the positron from reaching the inner parts of the atoms. Therefore not all electrons are effective, so that N will lie between n and nZ , n being the number of atoms per unit volume. For lead $n = 3.3 \times 10^{23}$ which gives as lower limit for $R_2 = 2.5 \times 10^8$. To explain the intensity of the hard component we must therefore expect for the one quantum process a rate of the order 10^8 .

We have calculated the cross section for the destruction of the positron by the one quantum process. Since we are dealing with low velocity positrons one might expect that a nonrelativistic approximation⁴ will give at least the right order of magnitude. We find as the contribution to the cross section due to the K -shell of the atom, neglecting the screening by the atomic electrons:

$$\sigma_K = (4/3)\pi^2\alpha^3a^2Z^3(1+Z^2/W)\{\exp(2\pi Z/W^3)-1\}^{-1}, \quad (2)$$

where α is the fine structure constant, a is Bohr's radius and W is the energy of the positron expressed in Rydbergs. The contribution of the L -shell is considerably smaller; we find:

$$\sigma_L = (1/24)\pi^2\alpha^3a^2Z^3(4+7Z^2/W)\{\exp(2\pi Z/W^3)-1\}^{-1}. \quad (3)$$

From these cross sections we find the rate of destruction by multiplying with nv . For positrons of low velocity it is not permissible to neglect the screening, because the exponential factor which is the main term in (2) and (3) and is due to the repulsion of the positron by the nuclear charge, is essentially reduced by the screening. Using the statistical model one can show that instead of $\exp(-2\pi Z/W^3)$ one gets:

$$\exp\{-2.66Z^{1/3}\phi(0.442W/Z^{1/3})\}, \quad (4)$$

where $\phi(\xi)$ has the following values: $\phi(0) = 4.18$; $\phi(0.0018)$

$= 3.13$; $\phi(0.0158) = 2.63$; $\phi(0.122) = 1.96$; $\phi(0.425) = 1.48$; $\phi(1.31) = 1.06$ and $\phi(\xi) = (\pi/2)(\xi+1)^{-1/2}$ for larger values of ξ . For example in lead ($Z=82$) we get for resp. $W=1, 100, 10,000$, and $75,000$ ($=10^6$ volts) the following rates for destruction: $R_1 = 2 \times 10^{-5}, 10, 5 \times 10^7, 10^9$. The last value is only given as an indication, since the velocity is so high that (2) is no longer applicable.

The first value shows that the original explanation of the hard component as due to positrons which have completely lost their initial velocity cannot be maintained. We get a rate too small by a factor 10^{13} . One might perhaps still expect a very hard component due to the destruction of positrons at the beginning of their path, since the probability for destruction is then much higher. For an estimate, take positrons of 10^6 volts, which have a range in lead of 0.06 cm. The time required is about 3×10^{-12} sec., so that even if we assume during this time the maximum rate of 10^9 we get as total probability of destruction by the one quantum process 0.003. This would give of course radiation of about 2×10^6 volts. The probability is still very small, but one might perhaps hope that the relativistic corrections will increase this result appreciably.

We do not think however that this is very likely, because one needs an increase by a factor 100 to get an observable result. To estimate very roughly what the influence of relativity can be, we have made a numerical calculation of the cross section for destruction of positrons of 10^6 volt in lead. To simplify the calculation we have only considered the contribution due to transitions of s -states of the positron to s -states of the electron. In nonrelativistic approximation the rate is 0.4×10^9 . The relativistic calculation gave instead 2.3×10^7 . This of course does not necessarily mean that the relativistic result will really be smaller than the one given by the approximate formula (2), because we have many more transitions to take into account. But it makes one doubt if really the exact calculation will considerably increase the nonrelativistic result.

Finally one should of course not forget the probability of destruction by the two quantum process before the positron has lost its kinetic energy. This would give rise to a continuous band above 0.5×10^6 volts. The upper limit for this probability is however for lead and 10^6 -volt positrons only 5 percent and the actual value is probably less.

In conclusion our results are that it is difficult to reconcile the explanation of the hard component of Gray and Tarrant as due to the destruction of positrons with the Dirac theory.

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⁴ Nonrelativistic means here that nonrelativistic radial eigenfunctions are used, and that one keeps only the terms with the smallest power of $1/c$. This corresponds to the first formula of Oppenheimer and Plesset, which we have been able to check except that we got a result larger by a factor 2.