Fast Modulation Effects in the Optical Region

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IN these columns Forrester, Parkins, and Gerjuoy[1] have suggested the possibility of observing beat frequencies between closely neighboring lines in the optical region. They propose to detect microwave beats between two Zeeman components of a spectral line by allowing the light to fall on a photo-cathode. Thence, pulses of electrons go to a cavity in the same vacuum. It may be useful to call attention to the viewpoints presented in a paper by Breit, Ruark, and Brickwedde.[2] Experiments with rotating Nicols and other modulators were discussed on ordinary wave theory, and on the basis of absorption and emission by a large quantized rotating oscillator, representing the modulator. The analysis showed clearly that rays of different frequencies can be coherent and that the "only reason why we are not conscious of the fact is that their frequency differences are (ordinarily) too large. Thus, the Zeeman effect corresponding to 0.01 gauss would cause a frequency difference of the order of 10^5 a second, and hence no stationary pattern could be observed."

I wish to describe an interesting light-modulation experiment which I set up at the Bureau of Standards in 1926. It was not completed because of a change of residence. Light from a narrow slit fell on a lens of diameter D, the slit being at the focus. Behind the lens there was a mirror of width D rotating with a high angular velocity ω. Thus the reflected light could be swept rapidly over the narrow slit of a spectroscope, placed also at the focal distance. This experiment was designed to "cut photons in two." (The idea seemed sensible then, since Dirac's radiation theory had not been published.) Let us see what can be done to get very brief light pulses by this method. The lens forms a diffraction maximum of width $r\lambda/D$ at the focal distance r. Thus the effective duration of the pulse passing the final slit is $\lambda/D\omega$. Now, $D\omega/2$ is limited to a value of the order of 30,000 cm/sec. by the strength of present-day mirror materials; so, for green light, *the pulse duration cannot now be less than* 10^{-9} *sec., in order of magnitude.* This time interval is shorter than the duration of the fastest sparks, which must be superior to the decay time of the excited atoms, so this result may be interesting. Because of the short pulse length, the light transmitted has a relative band width $\Delta\lambda/\lambda = D\omega/c$, but if the mirror has a width equal to D there is a further broadening of the same magnitude, resulting from Doppler effect at the edges of the mirror face. The two effects are physically different, and not merely two ways of looking at the same thing. I have had the opportunity to discuss speedy rotators and short sparks with Drs. L. B. Snoddy and J. W. Beams, and wish to thank them for relevant information.

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[1] Forrester, Parkins, and Gerjuoy, Phys. Rev. 72, 728 (1947).
[2] Breit, Ruark, and Brickwedde, Phil. Mag. 3, 1306 (1927).

Gamma-Radiation from Light Nuclei under Proton Bombardment

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STUDIES of the gamma-radiation emitted in the disintegration of lithium, beryllium, carbon, and fluorine by protons at several well-known resonances have recently been completed. The thick-target yield of the radiation, the half-width of the resonance, and the range in aluminum of the secondary electrons produced by the radiation have been determined.

The results are tabulated in Table I. The resonance energies given in the second column are based on the resonance in $Li^7(p\gamma)$ at 440 kev as standard.* The values for the energy of the gamma-radiation which are listed are in most cases those which have been previously determined in this laboratory by magnetic analysis of the energy of secondary electrons and pairs produced in thin laminae suspended in a cloud chamber. The values have been corrected for new calibrations of the field coils used in these measurements. In the case of the 1077-kev resonance in $Be^9(p\gamma)$ the energy of the more energetic gama-ray (6.7 Mev) has been determined from secondary absorption measurements, while the 0.8-Mev radiation has been established in measurements employing a focusing beta-ray spectrometer.

The secondary ranges given in the table have been determined with coincidence counters and are those ranges at which the number of secondaries is reduced to 0.8 percent (2^{-7}) of the number without absorber between the counters.[1,2] The high order intersections of the absorption curves with the background are about 10 percent greater than these ranges but cannot be determined as accurately.

The thick-target yield of the radiation has been determined simultaneously with electroscopes and counters housed in aluminum. In the calculations we used the curves of Fig. 1, which give the counts per incident quantum produced in a counter and the ion pairs/cc per quantum/cm^2 produced in the ionization chamber of an electroscope as a function of the quantum energy. The quantum efficiency curve for a counter with aluminum walls was calculated from 2.5 to 25 Mev in a manner described by Bleuler and Zünti[2] and will be discussed in detail in a future publication. The electroscope curve is taken from Streib, Fowler, and Lauritsen.[3]

The yields are in disintegrations per incident proton for the actual targets employed, namely, LiOH with the natural Li^7 abundance, beryllium metal, natural Acheson graphite, and CaF_2. In the case of $C^{13}(p\gamma)$ there are 50 percent more quanta than disintegrations, since the disintegration branches about equally to give one 8.1-Mev quantum and one 2.3-Mev quantum followed by a 5.8-Mev quantum.[4] It is well to note that the approximate linearity of the detector sensitivity curves with energy makes the disintegration yield relatively independent of the branching or the number of steps in the radiation as long as the total energy radiated in the various transitions is the same.

Table I. Summary of Yield and Energy Measurements.*

Source	Resonance energy kev	Energy of radiation Mev	Range of secondaries d_T (Al) cm	Thick-target yield Electroscope	Thick-target yield Counter	$\omega\gamma$ ev	Γ kev	σ_R cm^2
				Disintegrations/proton	Disintegrations/proton			
$Li(p\gamma)$	439	17.5[a]	2.91	5.6×10^{-9}	5.1×10^{-9}	8.9	12[d]	5.7×10^{-27}
$Be^9(p\gamma)$	988	7.4	1.26	1.82×10^{-8}	1.74×10^{-8}	12.5	94	4.4×10^{-28}
	1077	6.7,0.8	1.11	1.05×10^{-9}	0.97×10^{-9}	0.77	4	5.8×10^{-28}
$C^{12}(p\gamma)$	453	2.3[b]			7.3×10^{-10}	0.63	35	1.2×10^{-28}
$N^{13}(\beta^+)$		1.25[c]			7.2×10^{-10}			
$C^{13}(p\gamma)$	550	2.3,5.8,8.1			1.8×10^{-10}	15	40	2.0×10^{-27}
$F^{19}(p\alpha', \gamma)$	338	6.3		1.67×10^{-8}	1.74×10^{-8}	30	4	6.5×10^{-26}
	All ≤960	6.3	1.06	6.80×10^{-7}	6.95×10^{-7}			

* Target materials: LiOH, Be metal, Acheson graphite, CaF_2.
[a] Weak radiation near 14 Mev neglected in these calculations.
[b] Plus two annihilation quanta.
[c] Maximum energy of the positrons.
[d] Corrected for radiation observed above resonance.

The agreement between electroscope and counter yields is satisfactory. In the carbon[5] and lithium[6] reactions the results do not depart markedly from the widths and yields which have been determined previously. In the case of $C^{12}(p\gamma)$ which results in the production of radioactive N^{13} the positron yield has been measured with counters and is in agreement with the quantum yield. In the $F^{19}(p\alpha', \gamma)$ reaction the yield values are 20 percent higher than that given for the alpha-particles by Van Allen and Smith[7] ($1.43 \times 10^{-8}\alpha/p$), and further studies of this discrepancy are contemplated.

From the absolute thick-target yields it is possible to compute the term $\omega\gamma = \omega\Gamma_p\Gamma_x/\Gamma = 2\epsilon Y/\lambda^2$, which appears in the Breit-Wigner dispersion formula. The quantity ω is the statistical factor, Γ_p is the width for re-emission of a proton, Γ_x is the width for the primary process in the gamma-radiation ($\Gamma_{\alpha'}$ in the case of fluorine, Γ_γ in all the others), and Γ is the width for all competing processes. Y is the yield, λ is the wave-length of the incident protons at resonance, and ϵ is the stopping cross section of the target for protons per disintegrable nucleus. The quantity γ is approximately equal to the smaller of Γ_p and Γ_x when $\Gamma = \Gamma_p + \Gamma_x$ and is thus equal to Γ_γ in all but the $F^{19}(p\alpha', \gamma)$ case where it is equal to Γ_p.

The width at resonance, Γ, has been determined for the case of lithium and carbon from the thick-target curves and in the case of beryllium from thin-target curves. The proton beam was passed through the electrostatic analyzer previously described[8] and had a spread in energy of the order of 300 e-volts at 1 Mev. In the case of carbon the widths are great enough so that the curves are distorted by the proton barrier penetration factor from that of a simple dispersion curve, and a correction has been made to give the width at resonance. A similar correction has been made for the position of the resonance. The total width is approximately equal to Γ_p in all but the $F^{19}(p\alpha', \gamma)$ case where it is equal to $\Gamma_{\alpha'}$.

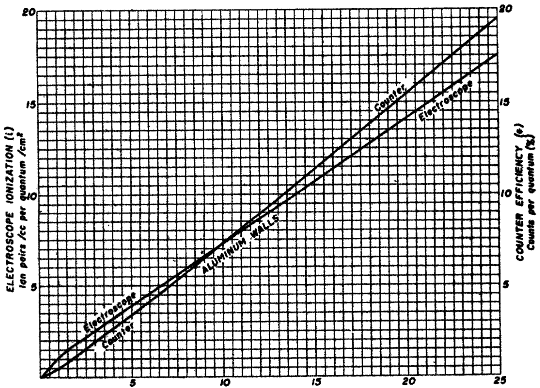

Fig. 1.

The theoretical implication of these results will be discussed in a future publication. The experimental results should serve to aid in standardizing information concerning the disintegrations of light elements. This work was carried out under contract with the Office of Naval Research.

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* A correction for radiation observed above the resonance indicates that the true resonance position is 439 kev on the conventional energy scale.

[1] Bradt, Gugelot, Huber, Medicus, Preiswerk, and Scherrer, Helv. Phys. Acta **19**, 77 (1946).

[2] E. Bleuler and W. Zünti, Helv. Phys. Acta **19**, 375 (1946).

[3] J. F. Streib, W. A. Fowler, and C. C. Lauritsen, Phys. Rev. **59**, 253 (1941).

[4] T. Lauritsen, C. C. Lauritsen, and W. A. Fowler, Phys. Rev. **59**, 241 (1941).

[5] R. B. Roberts and N. P. Heydenburg, Phys. Rev. **53**, 374 (1938); S. C. Curran, P. I. Dee, and V. Petržílka, Proc. Roy. Soc. **169A**, 269 (1939).

[6] L. R. Hafstad and M. A. Tuve, Phys. Rev. **48**, 306 (1935); W. A. Fowler, E. R. Gaerttner, and C. C. Lauritsen, Phys. Rev. **53**, 628 (1938).

Superconductivity and the Debye Characteristic Temperature

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A PAPER[1] with the above title was published recently in the Physical Review. In this paper a curve is drawn showing the relation between the superconducting threshold temperature (T_s) and the Debye characteristic temperature (Θ_D), and some conclusions are derived on the basis of this assumption. If this relation is justifiable we could also say that substances which do not become superconducting by about 0.7°K will not become superconducting at all. This conclusion is not drawn in the paper mentioned, but a similar conclusion was drawn in an