Walter and Barratt[1] examined and identified the absorption spectra of Li_2, Na_2, K_2, Rb_2, Cs_2, LiK, LiRb, LiCs, NaK, NaRb, NaCs, KRb, RbCs, and KCs.

The identification of a NaLi molecule is complicated by the existence of Na_2 and Li_2 band systems in the regions of the visible, near infrared and ultraviolet. Since the probability of molecular formation is a function of the product of the concentration of the atoms involved, it seemed possible that one component of a sodium-lithium mixture might be held at a low vapor pressure and the other at a high vapor pressure to increase the probability of observing the NaLi molecule.

In our experiment the lithium metal was placed in an absorption cell constructed of nickel and having water-cooled quartz windows. A nickel side tube was connected to the absorption cell to contain the sodium. Heating units were arranged around the absorption cell and side tube to control the temperature of the sodium and lithium metals independently.

The lithium metal was maintained at 850°C. A series of absorption spectrograms was then taken with the sodium at temperatures of 435, 460, 485, and 510°C, respectively. A similar procedure was used for maintaining constant high sodium with increasing lithium vapor pressures.

The results of this experiment confirm the previous work of Walter and Barratt. No bands attributable to a NaLi molecule were observed in the region 3000 to 8000A. No explanation is available, particularly as it is the only member not observed of the complete set of binary molecular systems obtainable with the alkali metals.

* Contribution No. 10, Department of Physics, Kansas State College, Manhattan, Kansas.
† Now at Airport Station, Weather Bureau, Memphis, Tennessee.
‡ Now at South Dakota State College, Brookings, South Dakota.
[1] J. M. Walter and S. Barratt, Proc. Roy. Soc. (London) **A119**, 257 (1928).

Photo-Production of Neutral Mesons in Nuclear Electric Fields and the Mean Life of the Neutral Meson*

H. Primakoff†
Laboratory for Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts
January 2, 1951

It has now been well established experimentally that neutral π-mesons (π^0) decay into two photons.[1] Theoretically, this two-photon type of decay implies zero π^0 spin;[2] in addition, the decay has been interpreted as proceeding through the mechanism of the creation and subsequent radiative recombination of a virtual proton anti-proton pair.[3] Whatever the actual mechanism of the (two-photon) decay, its mere existence implies an effective interaction between the π^0 wave field, φ, and the electromagnetic wave field, **E**, **H**, representable in the form:

$$\text{Interaction Energy Density} = \eta(\hbar/\mu c)(\hbar c)^{-\frac{1}{2}}\varphi\mathbf{E}\cdot\mathbf{H}. \tag{1}$$

Here φ has been assumed pseudoscalar, the factors $\hbar/\mu c$ and $(\hbar c)^{-\frac{1}{2}}$ are introduced for dimensional reasons ($\mu \equiv$ rest mass of π^0), and η is a dimensionless constant determined by the decay mechanism.[4]

One can obtain η immediately (by a first-order perturbation calculation) in terms of the mean life, τ, of a neutral π-meson at rest, *viz.*:[5]

$$\tau^{-1} = \pi^2\eta^2\mu c^2/2\hbar. \tag{2}$$

The effective interaction of Eq. (1) can now be used for a calculation of the probability of the inverse process: π^0 production in photon-photon collisions, or, for the calculation of the probability of the more interesting process: π^0 production in the collision of a photon with an external, approximately static electric field; e.g., the Coulomb field of a (slowly recoiling) nucleus. The total cross section σ for this last process is, from a first-order perturbation treatment of Eq. (1), proportional to η^2; i.e., to τ^{-1}; one obtains[6]

$$\sigma \approx 32\pi^2\frac{\hbar/\mu c}{c\tau}Z\left(\frac{e^2}{\hbar c}\right)\left(\frac{\hbar}{\mu c}\right)^2\frac{4}{3}\left(\frac{\hbar\kappa}{\mu c}\right)^3, \quad \text{for} \quad \hbar\kappa \ll \hbar k \approx \mu c \tag{3}$$

$$\sigma \approx 32\pi^2\frac{\hbar/\mu c}{c\tau}Z^2\left(\frac{e^2}{\hbar c}\right)\left(\frac{\hbar}{\mu c}\right)^2, \quad \text{for} \quad R(k-\kappa) \approx \frac{(2Z)^{\frac{1}{3}}}{2}\frac{\mu c}{\hbar k} \ll 1. \tag{4}$$

In Eqs. (3) and (4), $\hbar k$, $\hbar\kappa = \hbar k[1-(\mu c/\hbar k)^2]^{\frac{1}{2}}$ are, respectively, the momenta of the incident photon and produced neutral π-meson; the angular distribution of the mesons is strongly collimated about the direction of the incident photon if $\hbar k \gg \mu c$. In deducing Eq. (3), it has been supposed that the nuclear protons remain approximately at rest during time intervals of the order of several periods of the incident electromagnetic wave [since $v_{\text{proton}} \approx \frac{1}{5}c$ and $(ck)^{-1} \lesssim \hbar/\mu c^2$], and that the probability of finding any pair of protons a distance r apart is proportional to $\exp(-r/R)$, where $R \approx \hbar(2Z)^{\frac{1}{3}}/\mu c$ is the nuclear radius. It is seen from Eqs. (3) and (4) that the electric fields of the Z protons contribute "coherently" to the π^0 production, once the photon energy exceeds $\frac{1}{2}(2Z)^{\frac{1}{3}}\mu c^2$.

Thus, if τ is less than, say, 10^{-17} sec, Eq. (4) indicates that a Z^2 term should be observable in the total cross section for production of neutral π-mesons in photon-nucleus collisions. Since no such term has so far been experimentally detected,[7] one can set a very rough lower limit on τ: $\tau > 5\times10^{-16}$ sec. An approximate upper limit of 5×10^{-14} sec seems to be indicated by cosmic-ray data.[8]

* Assisted by the joint program of the ONR and AEC.
† On leave from Washington University, St. Louis, Missouri.
[1] Steinberger, Panofsky, and Steller, Phys. Rev. **78**, 802 (1950); Panofsky, Aamodt, Hadley, and Phillips, Phys. Rev. **80**, 94 (1950).
[2] C. N. Yang, Phys. Rev. **77**, 243 (1950); D. C. Peaslee, Helv. Phys. Acta **23**, 845 (1950); we exclude the possibility of the π^0 spin being >1.
[3] J. Steinberger, Phys. Rev. **76**, 1180 (1949), and other references quoted there.
[4] Marshak, Tamor, and Wightman, Phys. Rev. **80**, 765, 766 (1950); K. Brueckner, Phys. Rev. **79**, 641, 187 (1950).
[5] The mechanism of π^0 decay via interaction with virtual proton anti-proton pairs gives, if for example γ_5 coupling is used between the meson and nucleon wave fields, $\tau^{-1} = (\mu c^2/16\pi^2\hbar)(\mu e^2/M\hbar c)^2(g^2/\hbar c)$ (reference 3), so that in this case, $\eta = (\mu/8^{\frac{1}{2}}\pi^2 M)(g^2/\hbar c)^{\frac{1}{2}}(e^2/\hbar c)$.
[6] Another possible process predicted from Eq. (1) involves the one-photon decay of a π^0 in an external (nuclear) electric field. If τ' is the mean life of this decay, one obtains (with N as the number of nuclei per unit volume, and using Eq. (4))

$$\tau/\tau' = \tau c N\sigma 2k^2[\kappa^4 + (\mu c\kappa/\hbar)^2]^{-\frac{1}{2}} \approx 64\pi^2 Z^2(e^2/\hbar c)(\hbar/\mu c)^3 N \ll 1.$$

[7] Observations of Steinberger, Panofsky, and Steller quoted by R. F. Mozley, Phys. Rev. **80**, 493 (1950).
[8] Carlson, Hooper, and King, Phil. Mag. **41**, 701 (1950).