# 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 eighteenth of the preceding month, for the second issue, the third of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.*

**Communications should not in general exceed 600 words in length.**

## On the Binding of Neutrons and Protons

In a recent paper[1] Morse, Fisk and Schiff have discussed by exact solutions the several neutron-proton interaction problems, when the interaction is assumed to be

$$J(r_{ij})=-2D\exp\left[(2/r_0)(r_1-r_{ij})\right]+D\exp\left[(4/r_0)(r_1-r_{ij})\right],$$

where, for $r_1>0$, the field is attractive for large $r$, repulsive for $r<r_1$. It may be of interest to report the corresponding variational calculations for $H_3$ and $He_3$.

We first minimize the average Hamiltonian of the deuteron with the trial wave functions $e^{-\beta r}$ and $e^{-\beta r}+C\cdot e^{-\gamma r}$. The use of the former gives better than 95 percent of the true binding energy as calculated exactly. The latter function gives inappreciably better results. In the $H_3$ problem we assume, to begin, that interaction takes place only between neutron and proton. We then apply the wave function

$$\psi=e^{-\mu(r_{12}+r_{13}+\sigma r_{23})}$$

(where particle 1 is the proton in the $H_3$ nucleus) in the equation

$$\left[\tfrac{1}{2}(\nabla_1^2+\nabla_2^2+\nabla_3^2)+W-J(r_{12})\cdot P_{12}{}^M-J(r_{13})\cdot P_{13}{}^M\right]\psi=0$$

when $P_{ij}{}^M$ is the Majorana operator. The calculation of the average Hamiltonian $H_{\text{av}}$ is facilitated by use of the expression

$$\int_v \frac{e^{-\alpha r_{12}-\beta r_{13}-\gamma r_{23}}}{r_{12}r_{13}r_{23}}dv_1dv_2dv_3=\frac{64\pi^3\cdot v}{(\alpha+\beta)(\beta+\gamma)(\gamma+\alpha)}.$$

Similar integrals with other combinations of $r$'s in the denominator are readily obtained by differentiating or integrating this expression with respect to $\alpha$, $\beta$ or $\gamma$.

$H_{\text{av}}$ has been minimized for values of $r_0$ from 0.1 to 1.0 nuclear units ($8.94\times10^{-13}$ cm) and for several values of $r_1/r_0$. We have kept away from limitingly small values of $r_0$ for as $r_0\rightarrow0$ one can obtain arbitrarily large values of binding energy (cf. L. H. Thomas).[2] In no case is $H_{\text{av}}$ greater than about $\frac{1}{2}$ the observed binding energy. The variational method can hardly be in error by more than a few percent in this range of $r_0$, hence, we are led to the conclusion that there must exist a neutron-neutron attraction.[3]

Assuming the neutron-neutron force proportional to the neutron-proton, where $D'$ is the depth of the $J(r_{nn})$ hole, we recalculate $H_{\text{av}}$ for several values of the ratio $D'/D$. The results are shown in Fig. 1. We see that $D'/D$ must be between $\frac{1}{3}$ and $\frac{1}{2}$ in order to give the correct binding energy of $H_3$ ($W=16$) with a reasonable value of $r_0$ (deduced from other considerations). Similar calculations were carried out for $r_1/r_0=\frac{1}{4}, \frac{1}{2}$. No appreciable differences in the values of $H_{\text{av}}$ were obtained for corresponding values of $r_0$.

The calculations for $He_3$ were carried out on the assumption that $J(r_{pp})$ differs from $J(r_{nn})$ only in a term, $E_c$ representing the coulomb repulsion. It was found that the magnitude of $E_c$ for the $r_0$ which best fitted the experimental binding energy of $H_3$ was 1.12 nuclear units. This is in fair agreement with the experimental value.

The integrations of the $He_4$ problem cannot be carried out if we employ a wave function connecting all of the particles. From the results of the three-body problems, we can, however, draw certain conclusions which, in conjunction with the paper previously mentioned,[1] give a fairly complete survey of an interesting type of interaction:

(i) Neutron-neutron interaction is necessary and must be made roughly a third to a half of the triplet neutron-proton interaction. The singlet neutron-proton interaction as obtained from scattering[1] is about equal to the (singlet) neutron-neutron interaction. This is in agreement with the recent work of Breit and Feenberg.[4]

(ii) The assumption that neutron-neutron interaction differs from proton-proton interaction only in the coulomb term, $E_c$, seems to be justified, and is consistent with calculations on proton-proton scattering.[5]

(iii) There is little difference in the results (at least for the light nuclei here considered) obtained from Wigner- and Majorana-type interactions.

(iv) The introduction of a central region of strong repulsion has little effect on the binding energies. (Such a model would prevent the collapse of heavy nuclei without the introduction of a Majorana operator, but we have been unable to construct a satisfactory argument to show that

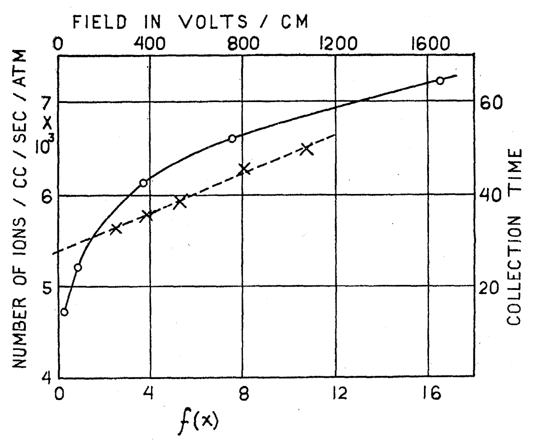


FIG. 1. The variational binding energy of $H_3$ *vs.* the "effective radius of interaction," $r_0$, for several values of $D'/D$, the ratio of depths of neutron-neutron to neutron-proton holes.

the binding energies of heavier nuclei would increase linearly with the number of particles, or that a particularly stable $\alpha$-particle would exist, without retaining the Majorana operator.)

(v) Good results for the binding energies of $H_3$ and $He_3$ can be obtained by the present method when the parameters are adjusted to fit the binding energy of the deuteron; at the same time maintaining consistency with the results of reference 1.

These results, which were obtained independent of the recent work of Present,[6] are consistent with his results, but represent somewhat greater generality, in that allowance is made for a region of strong repulsion between the particles.

All of these calculations arose through our numerous discussions with Professor P. M. Morse, to whom we are indebted.

J. B. FISK, Society of Fellows, Harvard University,
L. I. SCHIFF, Massachusetts Institute of Technology,
W. SHOCKLEY, Bell Telephone Laboratories.

November 15, 1936.

[1] Morse, Fisk, and Schiff, Phys. Rev. **50**, 748 (1936).
[2] L. H. Thomas, Phys. Rev. **47**, 903 (1935).
[3] See Feenberg, Phys. Rev. **47**, 857 (1935).
[4] Breit and Feenberg, Phys. Rev. **50**, 850 (1936).
[5] Breit, Condon and Present, Phys. Rev. **50**, 825 (1936).
[6] Present, Phys. Rev. **50**, 635 (1936).

## Ionization Potentials of Free Radicals

Measurements of the ionization potentials of certain polyatomic molecules by a molecular beam method have already been reported.[1] These measurements have now been extended to include the free radicals $CH_3$ and $C_2H_5$. The free radicals were formed in the source by the thermal decomposition of the corresponding tetra-alkyl leads.[2] The beam of free radicals, defined in the usual way by source and image slits, was received in a specially designed ionization gauge. This form of detector has been found more suitable for use with free radicals than the Kingdon cage previously employed.[1]

Curves relating anode potential and positive ion current were obtained, the voltage scale being calibrated against methyl iodide, I.P. = 9.489 volts.[3] Extrapolation of these curves to meet the voltage axis gave: I.P. ($CH_3$) = 11.1 volts, I.P. ($C_2H_5$) = 10.6 volts; the estimated limits of error being $\pm 0.5$ volt.

It is possible to form an indirect estimate of the ionization potential of $CH_3$ on the basis of existing experimental data. Hogness and Kvalnes[4] and Hipple and Bleakney[5] have determined the appearance potential of $CH_3^+$, formed by electron bombardment of $CH_4$, as 15.5 and 14.7 volts, respectively. Norrish,[6] from a consideration of thermal and spectroscopic data, obtains 4.5 volts as the energy of the C−H bond. Direct subtraction of the bond energy from the appearance potential yields 11 volts (H. and K.) or 10.2 volts (H. and B.) for the ionization potential of $CH_3$, in substantial agreement with our directly determined value.

Mulliken's theoretical estimate is 8.5 volts.[7] He suggests that this value may be brought into line with the appearance potential data by assigning some 2 volts internal or kinetic energy to the products of the reaction $CH_4 \rightarrow CH_3^+ + H$. It appears from our results, however, that a few tenths of a volt at most can be accounted for in this way.

A full account of our experiments will appear elsewhere.

R. G. J. FRASER
T. N. JEWITT

Laboratory of Physical Chemistry,
Cambridge, England,
October 24, 1936.

[1] T. N. Jewitt, Phys. Rev. **46**, 616 (1934).
[2] F. Paneth and W. Hofeditz, Berichte **62**, 1335 (1929); F. Paneth and W. Lautsch **64**, 2702 (1931).
[3] W. C. Price, J. Chem. Phys. **4**, 539 (1936).
[4] T. R. Hogness and H. W. Kvalnes, Phys. Rev. **32**, 942 (1928).
[5] J. A. Hipple and W. Bleakney, Phys. Rev. **47**, 802 (1935).
[6] R. G. W. Norrish, Trans. Faraday Soc. **30**, 106 (1934).
[7] R. S. Mulliken, J. Chem. Phys. **1**, 492 (1933).

## The Shortest Continuous Radio Waves

An investigation was undertaken to determine the practical short wave limit for electromagnetic waves produced by vacuum tubes. Stable continuous waves of 0.64 cm wave-length were produced by means of a split anode magnetron operating in the electronic mode of oscillation. The wave-length was measured to within one percent by an echelette grating spectrometer, which has been described in previous papers.[1] The receiver was an iron pyrite crystal connected to a sensitive galvanometer.

The table gives information concerning the construction and operation of three microray tubes designed to operate at wave-lengths below 2 cm. $R_a$ is the anode radius in cm, $L$ is the distance in cm from the shorting bar on the Lecher frame to the filament, $V$ is the anode potential in volts, $H$ is the magnetic field strength in oersteds, and $\lambda$ is the wave-length in cm.

| TUBE No. | $R_a$ | $L$ | $V$ | $H$ | $\lambda$ |
|---|---|---|---|---|---|
| 1 | 0.045 | 0.99 | 830 | 6,600 | 1.87 |
| 2 | 0.035 | 0.75 | 1350 | 9,900 | 1.22 |
| 3 | 0.019 | 0.38 | 1200 | 24,000 | 0.64. |

The tube producing the shortest wave-length (No. 3) produced about $4 \times 10^{-9}$ ampere in a crystal detector placed at the focus of the receiving mirror, and at a distance of 15 meters from the tube. In order to obtain the magnetic field necessary to operate tube No. 3, the elements were enclosed in an envelope whose outside diameter was 0.45 cm.

It may be concluded that continuous electromagnetic waves may be produced as short as 6 mm by means of a split anode magnetron, and that the lower limit is determined by the strength of the magnetic field which it is practicable to obtain. The tubes will operate with sufficient stability and output to serve as sources of electromagnetic radiation for many researches in this wave-length region.

C. E. CLEETON
N. H. WILLIAMS

University of Michigan,
Ann Arbor, Michigan,
November 16, 1936.

[1] Cleeton and Williams, Phys. Rev. **44**, 421 (1933); Cleeton and Williams, Phys. Rev. **45**, 234–237 (1934); Cleeton, Physica **6**, 207–209 (1935).