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¹ H. A. Tolhoek, *Revs. Modern Phys.* **28**, 277 (1956).

² A. Bincer, *Phys. Rev.* **107**, 1434 (1957).

³ G. W. Ford and C. J. Mullin, *Phys. Rev.* **108**, 477 (1957).

⁴ *Note added in proof.*—We have been informed that the differences between our results and those of Ford and Mullin are due to two typographical errors in their paper. See G. W. Ford and C. J. Mullin, *Phys. Rev.* **110**, 1485(E) (1958) this issue.

Number of 3d Electrons in the Transition Metals*

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AT a recent conference, values were presented for the number of 3d electrons in Cu, Ni, Co, Fe, and Cr,¹ in the solid state as obtained from absolute measurements of the scattering factor for x-rays. Inasmuch as the results differ considerably from the well-known atomic configurations, they occasion some curiosity, as the authors have remarked.¹ Furthermore, the configurations advocated in reference 1 are difficult to reconcile with self-consistent calculations for the valence band-wave functions of the transition elements.² The interpretation of the experiments by Weiss and DeMarco rest on two assumptions. First, it is assumed that the contribution to the scattering by the "argon core" electrons may be assessed by means of a self-consistent field calculation for the free atom. Next, it is assumed that the extent of the 3d wave functions is greatly exceeded by that of the 4p and 4s so that the latter may be neglected. It is then the case that the scattering in excess of that for the "argon core" is due only to the 3d electrons. The last assumption may possibly be questioned and it would seem desirable to obtain some independent information on the number of 3d electrons per atom in the transition elements in the solid state. It is the purpose of this note to point out that some such information exists already in the literature and tends to favor the conventional configurations assigned to the atoms in the metal over those suggested by Weiss and DeMarco.

Several years ago Nilsson³ observed that the excitation function for K series characteristic x-radiation from the transition elements exhibited a region fairly rich in structural detail over a few tens of volts from the excitation potential. A particular feature of interest here was termed by Nilsson the "h structure." It gives the appearance of a partially resolved "line" occurring slightly below the Fermi energy as determined from the results of Beeman and Friedman.⁴ Nilsson interpreted this line as due to ionizing transitions in which the electron final state lies in the unfilled part of the 3d band. Its intensity would then be expected to vary

with the filling of the 3d band and Nilsson observed this to be the case, assuming conventional configurations appropriate to the atoms in the metal.

A specific example may be taken from a comparison of Co and Fe. According to the assignments of Weiss and DeMarco, the line would be expected to be about four times as intense in Fe as in Co. The observed factor is approximately $\frac{1}{3}$ which would have been expected on the basis of conventional atomic configurations in the metals.

It is suggested that since in the scattering experiments there are no selection rules effective in sorting states of a special symmetry, those experiments yield only some measure of the total extent of the electron cloud. Distinction among symmetry types is more properly sought in spectroscopic measurements.

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¹ R. J. Weiss and J. J. DeMarco, *Revs. Modern Phys.* **30**, 59 (1958).

² J. Callaway (private communication).

³ A. Nilsson, *Arkiv Fysik* **6**, 513 (1953).

⁴ W. W. Beeman and H. Friedman, *Phys. Rev.* **56**, 392 (1939).

μ -Mesonic Molecular Ions and Nuclear Catalysis*

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THE experimental observation^{1,2} of the catalysis of nuclear reactions by μ mesons in liquid hydrogen³ created interest at a number of laboratories and led to several independent theoretical investigations of the processes involved.⁴ Although it soon became clear that this phenomenon could not lead to the production of useful power, some of the estimates of particular reaction rates were in wide disagreement, primarily because of the gross approximations made. Because of the intrinsic interest in the effect, and in order to obtain a more satisfactory understanding of these processes, we have made a detailed investigation of the molecular systems involved in these reactions.

It is assumed that nuclear catalysis proceeds through the following processes:

(1) The μ meson is slowed down by collisions in the liquid hydrogen and captured by a proton, forming a ($p\mu$) atom.

(2) The ($p\mu$) atom migrates and encounters a deuteron which captures the meson by exchange. Owing to the difference in reduced mass, this process releases 135 ev to the system.

(3) The ($d\mu$) atom slows down by collisions and forms a ($p\mu d$)⁺ molecular ion by a process of electron ejection.

(4) The nuclear reaction $p+d \rightarrow \text{He}^3 + \gamma$ (5.5 Mev) occurs. The γ ray may then eject the meson.

In all these processes there is competition with the natural decay of the meson, while in processes (2) and (3) there is also a competition with the formation of other molecular ions, such as $(p\mu p)^+$ and $(d\mu d)^+$.

In our investigations of the molecular ions, we have used the Born-Oppenheimer approximation⁵ as a starting point for a variational calculation of the bound-state and scattering wave functions of the three-body system. In this calculation, corrections to first order in the ratio of mesonic to nucleonic mass were included.

TABLE I. Calculated binding energies of bound states of μ -mesonic molecular ions.

System	State	Binding energy (ev)
$(p\mu p)^+$	$L=0$	2771
	$L=1$	2624
$(p\mu d)^+$	$L=0$	2878
	$L=1$	2754
$(d\mu d)^+$	$L=0$	2986, 2845
	$L=1$	2887
	$L=2$	2746

In the unequal-mass case, $(p\mu d)^+$, this leads to a pair of coupled second-order differential equations, while in the equal-mass cases, $(p\mu p)^+$ and $(d\mu d)^+$, the two equations are not coupled. The solutions to these equations were carried out numerically by use of an IBM-701 computer. The wave functions and eigenvalues for all the bound molecular-ion states were obtained. These binding energies relative to the totally separated systems are given in Table I.

The free-state wave functions were also calculated, and the energy dependences of the scattering cross sections were investigated. The results of these calcu-

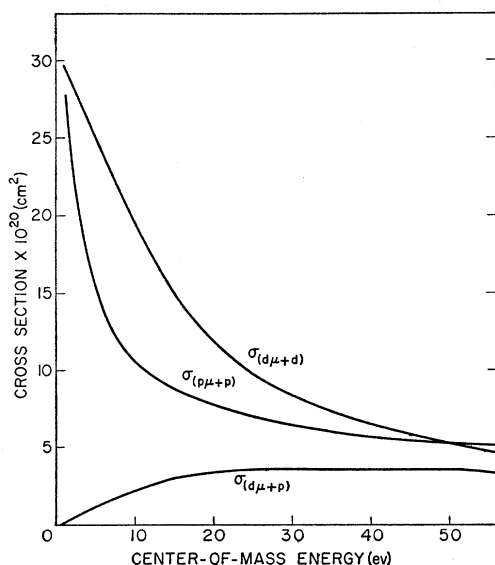


FIG. 1. The energy dependence of elastic-scattering cross sections for μ -mesonic atoms from protons and deuterons.

lations are shown in Fig. 1. Of particular interest is the anomalous behavior of the scattering cross section for $(d\mu)$ atoms on protons. For energies in the thermal range this cross section is extremely small, corresponding to a scattering length ~ 0.08 times the mesonic Bohr radius. The unusually long gaps between the ending of the initial meson track and the beginning of the secondary track which were observed experimentally¹ can probably be explained by such a Ramsauer effect. In addition, the exchange cross sections were calculated, giving for process (2) an exchange rate R_{ex} near zero energy of $11.5 \times 10^9 \text{ sec}^{-1}$ in pure liquid deuterium.

From the wave functions, estimates for rates of molecular-ion formation at low energies were also obtained. These are as follows:

$$(p\mu) + H \rightarrow (p\mu p)^+ + e, \\ R_{2m} = 8 \times 10^6 \text{ sec}^{-1} \text{ (in liquid hydrogen);}$$

$$(d\mu) + H \rightarrow (d\mu p)^+ + e, \\ R_{3m} = 3 \times 10^6 \text{ sec}^{-1} \text{ (in liquid hydrogen).}$$

By a phenomenological analysis of the experiments one can determine the ratio $R_{ex}/(R_{2m} + R_{\mu})$, where R_{μ} is the natural meson-decay rate. Our calculated value for this ratio is 1.3×10^3 , in good agreement with the experiments.

A full account of these calculations will be published.

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⁵ M. Born and J. R. Oppenheimer, Ann. Physik **84**, 457 (1927).

Measurement of Spins of Levels Excited by Slow Neutron Capture*

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THE spectrum of the gamma rays following neutron capture in individual resonances can be used to determine the spin of the levels corresponding to the resonances in certain favorable cases.¹ We are here reporting results in which the method has been successfully applied to the determination of the spins of several levels in W^{184} . For the target nucleus W^{183} , the gamma-ray transitions from the capturing state in the compound nucleus W^{184} to the ground state are strongly