totic value in the $X^2\pi$ ground states of the CH and CD doublet spectra has been observed by Gerö and the effect is shown by numerous limiting curves of predissociation.[1,2] The greater bond energy of the CD potential function is connected with a somewhat shorter observed equilibrium internuclear distance. The dependence of the potential function on the isotopic mass should be a quite general effect in all the diatomic hydrid and deuterid spectra.

For the observed rotational constants B, one has

$$B=(h^2/8\pi^2\mu)\int\bar{\phi}(1/r^2)\phi d\tau,$$

with $\mu=M_1M_2/(M_1+M_2)$, and in first approximation

$$B(CD)/B(CH)=\rho^2=\mu(CH)/\mu(CD).$$

Some effects causing slight deviations from this isotopic ratio of the rotational constants are dealt with in Van Vleck's review.[3] According to the observation of Gerö and Schmid, however, the rotational constants of diatomic hydrid and deuterid spectra show, in general, a deviation from this rule larger in order of magnitude than the effects given in Van Vleck's paper. One should also mention the remark of Sandeman,[4] who concluded from an analysis of the band constants of the D_2, DH, and H_2 spectra, that these three molecules have three different potential curves.

In order to obtain a suitable description of the interaction of the particles in a diatomic molecule, instead of the coordinates x_i'' of the electrons and X_1'', X_2'' of the nuclei one must introduce the relative coordinates $x_i'=x_i''-X_1''$, $X_r'=X_2''-X_1''$ of the particles related to one of the nuclei, besides the coordinates of the center of gravity, $X=(m\sum x_i''+M_1X_1''+M_2X_2'')/M$.[5] The total kinetic energy of the particles,

$$\frac{h^2}{8\pi^2}\Biggl\{\frac{1}{M}\Delta+\frac{1}{\mu}\Delta_r'+\frac{1}{m}\sum\Delta_i'+\frac{1}{M_1}\Biggl(\Bigl(\sum\frac{\partial}{\partial x_i'}\Bigr)^2+\Bigl(\sum\frac{\partial}{\partial y_i'}\Bigr)^2+\Bigl(\sum\frac{\partial}{\partial z_i'}\Bigr)^2\Biggr)+\frac{2}{M_1}\Biggl(\frac{\partial}{\partial X_r'}\sum\frac{\partial}{\partial x_i'}+\frac{\partial}{\partial Y_r'}\sum\frac{\partial}{\partial y_i'}+\frac{\partial}{\partial Z_r'}\sum\frac{\partial}{\partial z_i'}\Biggr)\Biggr\},\quad(1)$$

contains besides the first three terms corresponding to the kinetic energy of the center of gravity, of the relative nuclear motion and of the electrons, the last two small correction terms. Though these correction terms are not the most important ones from the point of view of isotopic effects, it is worth while to stress, for instance, in the case of CH and CD, that in taking the H or D nucleus as reference particle, their effect corresponds to terms explicitly containing the different masses M_1, whereas with the carbon nucleus as reference particle this part of the isotopic effect is already included in the molecular wave functions.

As pointed out in a previous paper,[6] owing to the influence of the nuclear motion on the electronic motions, clear distinction is to be made between the corresponding part of the potential function of an unperturbed electronic state,

$$V_I(r)=\int\bar{\phi}_e^{(\Omega)}(x_i,r)(T_e+U)\phi_e^{(\Omega)}(x_i,r)dx_i,\quad(2)$$

and the energy eigenvalue function of the fixed nuclei problem. The influence of the nuclear motion, represented by the second term in expression (1), on the wave function factor $\phi_e^{(\Omega)}(x_i,r)$ characterizing an unperturbed electronic state, may be considerable. Thus one can understand the observed isotopic effects which cannot be understood on the ground of the correction terms in a model in which this wave function factor is identified with an eigenfunction of the fixed nuclei problem.

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Products of High Energy Deuteron and Helium Ion Bombardments of Copper

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THIS communication summarizes the preliminary observations made when natural copper (stable mass numbers 63 and 65) was bombarded with 190-Mev deuterons and 380-Mev helium ions produced by the 184-inch frequency-modulated cyclotron.[2] After a 10- to 40-minute bombardment with a beam of about 0.5 microamperes for the deuterons or of unknown intensity for the helium ions, the spectrographically pure metallic copper target was dissolved in acid, inactive carrier elements added, and chemical separations performed until pure elemental fractions were isolated. Aliquots of these fractions were evaporated on platinum foil disks and the rate of decay carefully followed with a thin-window (*ca.* 3 mg/cm² mica) Geiger-Müller counter. Identification of radioactive product isotopes was made by these half-life determinations supplemented in most cases by at least one of the following methods: (a) observation of parent-daughter relationships when possible; (b) observation of the sign of the radiation by counting through a magnetic field; (c) rough energy determinations by counting through aluminum, beryllium, or lead absorbers; and (d) differential counting through different absorbers. The results of the deuteron bombardments are summarized in Table I.

Two previously unreported isotopes were found. Freshly precipitated zinc fractions showed a growth corresponding to *ca.* 11 minutes half-life, followed by a 9.5-hour decay. Removal of copper from the zinc fractions yielded in the copper fractions a pure 11-minute activity which was identified as Cu^{62}; the 9.5-hour activity was therefore assigned to Zn^{62}. The number of counts per minute of the 11-minute copper activity removed from the zinc fraction (extrapolated back to the time of separation) was the same within ±10 percent as the number of counts per minute of the 9.5-hour activity in the zinc-copper mixture immediately before copper-zinc separation. Since Zn^{62} was thus apparently detected only by virtue of the activity of its daughter, it is presumed to decay by orbital electron

TABLE I. Isotopes observed as products of the bombardment of natural copper with 190-Mev deuterons.

Isotope	Type of radiation[a]	Half-life Literature[b]	Half-life Observed	Yield[c] relative to Cu^{61}	Change in A and Z from Cu^{65}: A	Z
$_{30}Zn^{62}$	(K)	—	9.5 h.	0.035	−3	+1
Zn^{63}	(β^+)	38 m.	36 m.	0.05	−2	+1
$_{29}Cu^{60}$	(β^+)	24.5 m.[d]	*ca.* 25 m.	0.3	−5	0
Cu^{61}	β^+, (K)	3.4 h.	3.3 h.	1.0	−4	0
Cu^{62}	β^+	10.5 m.	*ca.* 11 m.	2.3	−3	0
Cu^{64}	(β^+, β^-, K)	12.8 h.	13 h.	0.6	−1	0
$_{28}Ni^{57}$	β^+	36 h.	37 h.	0.04	−8	−1
Ni^{65}	β^-	2.6 h.[e]	2.5 h.	0.04	0	−1
$_{27}Co^{55}$	β^+	18.2 h.	17 h.	0.04	−10	−2
Co^{61}	β^-	1.8 h.[f]	1.7 h.	0.14	−4	−2
$_{26}Fe^{52}$	β^+	—	7.8 h.	0.003	−13	−3
Fe^{53}	(β^+)	8.9 m.	9 m.	0.07	−12	−3
Fe^{59}	β^-	47 d.	49 d.	0.07	−6	−3
$_{25}Mn^{51}$	(β^+)	46 m.	45 m.	0.04[g]	−14	−4
Mn^{52}	β^+, (K)	6.5 d.	6 d.	0.1	−13	−4
Mn^{56}	β^-	2.59 h.	2.5 h.	0.15	−9	−4
$_{24}Cr^{49}$	β^+	41.9 m.	41 m.	0.01	−16	−5
Cr^{51}	(K)	26.5 d.	27 d.	*ca.* 0.02[g,h]	−14	−5
$_{23}V^{48}$	β^+, (K)	16 d.	16 d.	0.05[g]	−17	−6
$_{17}Cl^{38}$	β^-	37 m.	38 m.	0.0005	−27	−12
$_{15}P^{32}$	(β^-)	14.30 d.	15 d.	0.0005[g]	−33	−14

[a] Parentheses indicate that the sign of the radiation has not been directly observed in these investigations.
[b] Unless otherwise noted the reference is to Seaborg, Table of Isotopes, Rev. Mod. Phys. **16**, 1–32 (1944).
[c] A rough estimate indicates that a relative yield of one is equivalent to a cross section of the order of 10^{-25} cm^2.
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[f] Parmley and Moyer, Phys. Rev. **72**, 82 (1947).
[g] Results of only one bombardment. All other figures represent best values or averages resulting from two to seven bombardments.
[h] Corrected for amount formed by Mn^{51} decay.

capture; decay by a positron of energy too small to have been detected efficiently by our Geiger-Müller tubes is not ruled out, however. A 7.8-hour activity was noted in the iron fractions and was shown by iron-manganese separations to give growth to a 21-minute manganese daughter activity. An aluminum absorption curve of the parent-daughter equilibrium mixture showed, in addition to a component of *ca.* 2.3 Mev attributable to the 21-minute Mn^{52}, a component of *ca.* 0.55-Mev maximum energy presumably as a result of the 7.8-hour parent, assigned to Fe^{52}.

The yields for the radio-isotopes of any one element increase as the difference between the mass number of the product isotope and mass number of maximum stability for that element decreases; it seems probable that the total yield of stable isotopes is of the same order of magnitude as the total yield of radio-isotopes. In the most extensively investigated region, from chromium through zinc, practically all known radio-isotopes which could have been observed in view of half-life and experimental time considerations were identified. Intermittent deuteron bombardment of one target over a period of several months, in which the total bombardment was about 20 times that of the usual shorter bombardment, resulted in observation of long-lived activities (>70 d.), which have not been positively identified, in the zinc, cobalt, manganese, and titanium fractions. Assuming that the activities in the zinc, manganese, and titanium fractions are due solely to Zn^{65}(250 d. β^+, K), Mn^{54}(310 d. K), and Ti^{51}(72 d. β^-), the maximum relative yields are calculated to be 0.007, 0.12, and 0.0005, respectively. Since three or four isotopes are probably contributing to the long-lived activity in the cobalt fraction, a relative yield figure is of no significance. It is noteworthy that little or no positron activity was found in the chlorine fraction; the yield of Cl^{34}(33 m. β^+) is $\leqslant 0.00005$.

One bombardment with approximately 380-Mev helium ions (contaminated with about 20 percent deuterons) was conducted. The yields of the radio-isotopes in the fractions investigated (copper, iron, manganese, chromium, and chlorine) were in all cases except one within the range of the yields obtained from the several deuteron bombardments (within a factor of about 2). The exception was Cl^{38}, which was produced with a yield six times as great as that from deuteron bombardments.

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Notes on the Beta-Ray Spectra from Copper 64

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IN the investigation of beta-ray spectra one may meet with two possible sources of extraneous electrons: homogeneous internal conversion electrons, which are usually easily recognized as such, and electrons from internal pair production, which have a continuous distribution in energy. If pair electrons are present, and are not recognized as such, they may distort the experimentally obtained beta-ray distributions. This possibility is, therefore, worth excluding before experimentally obtained beta-ray spectra are compared with theoretical predictions.

Cook and Langer[1] have recently investigated the negatron and positron spectra from Cu^{64} by means of a high resolution spectrometer[2] as a test of the Fermi theory of beta-decay.[3] They found in the case of the negatrons a total excess of 6 percent slow negatrons (i.e., below app. 200 kev); and in the case of the positrons a total excess of 9 percent slow positrons (i.e., below app. 250 kev) above the numbers predicted by the Fermi theory. On a Kurie plot[4] these deviations show up in the low energy region as positive deviations from the expected straight-line graph, already found by other investigators.[5]

If one assumes the decay scheme of Cu^{64}, as shown in Fig. 1,[6] one can easily calculate that the percentage excess of slow negatrons found by Cook and Langer represents