Atomic partition functions for iron (*)

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Summary. — Numerical values of the atomic partition functions (APF), $U^{(r)}$, for FeI, FeII and FeIII are given for the temperature range 2000-40000 K, and for various lowering of the ionization energy (in the range 0.01 to 2.00 eV). In the calculations of the APF all quantum energy levels have been taken into account, including those lying above the normal ionization energy. Our values of APF are larger than those published previously, however, their ratios $U^{(r+1)}/U^{(r)}$ are smaller.

Key words : atomic partition functions — iron — plasma.

1. General remarks.

In the previous paper of the authors (Halenka and Grabowski, 1977, hereafter H-G) the problem of atomic partition functions (APF) calculations has been discussed in detail. The most general description of APF has been formulated (Eq. (2) in H-G), taking into account all the energy levels permissible by quantum mechanics (unlike the earlier APF definitions and calculations, e.g. Griem, 1964; Traving *et al.*, 1966; Drawin and Felenbok, 1965, hereafter D-F; see also for most complete APF tables Irwin, 1981). Also, an algorithm for the calculation of numerical values of APF has been proposed. It was applied to tin as an example, and its accuracy was checked. In particular we have shown that the contribution to APF of the levels above the normal ionization energy is not negligible. It should therefore be expected that the APF values hitherto published may be greatly underestimated, especially in the case of elements of complex energetic structure and of low ionization energy, e.g. elements of the first transition group (as Ti, V, Cr, Mn, Fe). In this paper the APF values have been calculated with the H-G technique for iron — one of the most important elements in astrophysical spectroscopy. We have maintained the calculation algorithm, the symbols and the terminology from H-G. Two additional points deserve comment : (1) the experimental data may be insufficient to determine « non-observed » levels by semiempirical methods; (2) the configurations of equivalent optical electrons cannot be taken directly into account by H-G formalism.

Comment 1 : this case occurs usually in higher ionization states. For FeIV, for example, in the tables of Moore (1949-1958), Reader and Sugar (1975) (hereafter R-S) and also Ekberg and Edlen (1978) (hereafter E-E), there are no levels of configuration (...)nd and later. In this case one can approximately estimate the quantum defects of « non-observed » levels — scaling the quantum structure in relation to other isoelectronic structures (for example, FeIV *vs.* CrII), where the relevant levels are known. For a given level sequence, denoted as (parent term)ns, (...)np, (...)nd, etc., the numerical values of the quantum defect δ decrease successively when the quantum number l increases, and attain practically zero at (...)ng configuration. This circumstance is helpful to estimate graphically the δ-values.

Comment 2 : to determine the « non-observed » levels belonging to the configuration of equivalent electrons (s^2, p^n, d^m) the semiempirical method employed in the H-G paper is useless. However, inspection of the above-mentioned tables suggests that for a given configuration — and for a configuration of equivalent electrons as well — the proportionality between the excitation energies of the corresponding isoelectronic terms is satisfied rather well. One can, therefore, scale the examined element by proper isoelectronic structures, in which the levels of interest are known. Figure 1 shows an example of a diagram for a well represented configuration d^4 of FeV (tables of R-S give all the terms) and of VII (Moore's tables contain all terms, except the ^1S).

Given term of a configuration of equivalent electrons usually belongs simultaneously to a few level sequences based on different parent terms. To calculate the contribution of the term examined, say, the j-th one, to the q-th partial APF (i.e. APF summed over the level sequence formed on the q-th parent term), one must multiply the

statistical weights of the levels of the term examined by their coefficients (conventionally normalized to 1) of the fractional parentage G_{qj} (the G_{qj}-value is the same for each i-th level of the j-th term). We have assigned the coefficients of the fractional parentage according to a well known procedure (cf. e.g. Slater, 1960, Vol. II; Sobelman, 1979) :

$$G_{qj} \equiv G_{\alpha' L' S'; \alpha LS} = (\alpha' \, L' \, S' ; \alpha LS)^2 \Big/ \sum{}'(\alpha' \, L' \, S' ; \alpha LS)^2 . \tag{1}$$

In the H-G paper each level sequence was based on one of the parent levels. In the configurations of the equivalent electrons, we generally are not able to ascribe a proper parent level (one of those forming the q-th parent term) to a given level of the j-th term examined. Fortunately, such ascription is not necessary to APF calculations. The H-G formulae, appropriate to the parent levels, can simply be adopted for the parent terms by summing over their component levels. Thus, the expressions (8), (8'), (9) and (10) in the paper H-G become :

$$\sum_{p \in \text{term } q} U_p^{(r)} = \sum_{p \in \text{term } q} \sum_{i=1}^{i_1(p)} g_{pi}^{(r)} \exp(- E_{pi}^{(r)}/kT) + \\ + \sum_{p \in \text{term } q} \Delta U_p^{(r)}, \tag{2}$$

where

$$\sum_{p \in \text{term } q} \Delta U_p^{(r)} = \\ = \sum_{p \in \text{term } k} \Delta U_p^{(r)} \frac{\sum\limits_{p \in \text{term } q} g_p^{(r+1)} \exp(- E_p^{(r+1)}/kT)}{\sum\limits_{p \in \text{term } k} g_p^{(r+1)} \exp(- E_p^{(r+1)}/kT)} \tag{2'}$$

and $g_{pi} = g_{p(q),i(j)} = (2 J_{pi} + 1) G_{qj}$;

$$\sum_{p=p_2}^{p_{\text{max}}} U_p^{(r)} = \\ = \left[\sum_{p \in \text{term } k} U_p^{(r)} \Big/ \sum_{p \in \text{term } k} g_p^{(r+1)} \exp(- E_p^{(r+1)}/kT) \right] \times \\ \times \left[U^{(r+1)} - \sum_{p=1}^{p_2-1} g_p^{(r+1)} \exp(- E_p^{(r+1)}/kT) \right]. \tag{3}$$

In the particular case when $E_{q=2}^{(r+1)}/kT \gg 1$ we have

$$U^{(r+1)}/U^{(r)} = \sum_{p \in \text{term } 1} g_p^{(r+1)} \exp(- E_p^{(r+1)}/kT) \Big/ \sum_{p \in \text{term } 1} U_p^{(r)} . \tag{4}$$

The sums run through all numbers p, ordering the levels of q-th, k-th and 1-th parent term. Of course, when we put $i_1(p) = i_{\max}(p)$, then the second term in equation (2) becomes $\sum_{p \in \text{term } q} \Delta U_p^{(r)} = 0$, because in the first term of the equation the sum over i runs through all numbers ordering the bound quantum levels. We maintain the division of the level sequences on the groups as in H-G. Equation (2) in the form mentioned above, should be used to calculate the contribution of the $\alpha^{(r)}$-th group of the level sequences to the APF-value. The level sequences which are formed on those of the parent terms, whose levels have ordering numbers p satisfying the inequality $p \leqslant p_1$, belong to the

$\alpha^{(r)}$ group. The level sequences based on parent terms whose ordering numbers p satisfy the inequalities $p_1 < p < p_2$, belong to the $\beta^{(r)}$ group. In this case equations (2) and (2') should be used. The next sequences belong to $\gamma^{(r)}$ group, for which equation (3) is appropriate.

2. Calculations.

To calculate the numerical values of APF, $U^{(r)}$, for the r-th ionization state, according to H-G's formalism, the values of $U^{(r+1)}$ must be known. Our purpose is to obtain the accurate U-values for FeI, FeII and FeIII.

To obtain reliable values of $U^{(3)}$, preliminary calculations were begun for FeV. $U^{(5)}$ has been roughly estimated by summation of the contributions over the FeV levels which are listed in R-S tables. In subsequent ionization states (FeIV up to FeI) the $U^{(r)}$ values have been calculated according to the H-G scheme with the modifications as described above. As a basis for the $E_{pi}^{(r)}$-values, the papers mentioned in the Comment 1 and the publication of S. Johansson (1978) (hereafter J) have been used. Thus, the level sequences have been divided into groups as noted below.

FeIV : $\alpha^{(4)}$-group : sequence on the parent (ground) term $3d^4$ (^5D), including levels of the configuration $3d^5$ (with G_{1j} coefficients).

$\beta^{(4)}$-group : sequences on the remaining parent terms of the $3d^4$ configuration, discrete summation of all levels of the configurations $3d^4 4s$, $3d^4 4p$ and $3d^5$ (with G_{qj} coefficients).

$\gamma^{(4)}$-group : remaining sequences.

FeIII : $\alpha^{(3)}$-group : sequence on the parent (ground) term $3d^5$ (^6S), including levels of the configuration $3d^6$ (with G_{1j} coefficients).

$\beta^{(3)}$-group : sequences on the remaining parent terms of the $3d^5$ configuration, discrete summation of all levels of the configuration $3d^6$ (with G_{qj} coefficients), of the configurations $3d^5 4s$, $3d^5 4p$ on the parent terms $3d^5$ $(^2J, \, ^2H, \, ^2D3, \, ^2F1, \, ^2G2, \, ^2F2, \, ^2G1, \, ^2S, \, ^2D2)$, and of the configurations $3d^5 4s$, $5s$, $6s$, $4p$, $5p$, $4d$ on the parent terms $3d^5$ $(^4G, \, ^4P, \, ^4F, \, ^4D)$.

$\gamma^{(3)}$-group : remaining sequences.

FeII : $\alpha^{(2)}$-group : sequence on the parent (ground) term $3d^6$ (^5D), including levels of the configuration $3d^7$ (with G_{1j} coefficients).

$\beta^{(2)}$-group : sequences on the remaining parent terms of the $3d^6$ configuration and of the parent configuration $3d^5 4s$, discrete summation of all levels of the configurations $3d^7$ (with G_{qj} coefficients), $3d^6 4s$, $3d^6 5s$, $3d^6 4d$, $3d^5 4s^2$, $3d^5 4s 4p$.

$\gamma^{(3)}$-group : remaining sequences.

FeI : $\alpha^{(1)}$-group : sequences formed on the parent terms $3d^6 4s$ (^6D), and $3d^7$ (^4F), including levels of the configurations $3d^6 4s^2$ and $3d^8$ (with coefficients G_{1j} and G_{2j} respectively).

$\beta^{(1)}$-group : sequences on the remaining parent terms of the $3d^7$ configuration and on the parent term $3d^6\,4s$ (^4D), discrete summation of levels from the configurations : $4d^7\,4s$, $3d^7\,4p$, and $3d^8$ (with coefficients G_{qj}), $3d^6\,4s$ (^4D) $5s$, $4p$, $5p$, $4d$, and $3d^6\,4s^2$ (with G_{qj} coefficients suitable for the parent term ^4D) [remaining levels on the parent terms of the $3d^7$ configuration have been calculated in comparison with the sequence on the parent term $3d^7$ (^4F), and remaining levels of the sequence on $3d^6\,4s$ (^4D) have been calculated in comparison with the sequence on the parent term $3d^6\,4s$ (^6D) (according to Eq. (2'))].

$\gamma^{(1)}$-group : remaining sequences (in comparison with the sequence based on the parent term $3d^6\,4s$ (^6D)).

In the cases of FeII, FeIII and FeIV in $\beta^{(r)}$ and $\gamma^{(r)}$ groups, the sequences based on ground parent terms (cf. $\alpha^{(r)}$) have been used for the purpose of comparison. Numerous levels among those included in $\alpha^{(r)}$ groups, and among the levels of $\beta^{(r)}$ whose contributions to APF have been included discretely, are not listed either in Moore's or in R-S, E-E and J tables. The energies of these levels have been determined by the method described in H-G or in the present paper.

The typical range of physical conditions of astrophysical and laboratory plasmas extends from 10^{12} to $10^{18}\,\text{cm}^{-3}$ in the electron concentration N_e and reaches 40000 K in the temperature T. As is well known, APF depends on N_e through the lowering of the ionization energy (LIE), $\Delta E^{(r)}$. In the current literature, various expressions are used for LIE (cf. e.g. Griem, 1964; Drawin and Felenbok, 1965; Lochte-Holtgreven, 1968; Gündel, 1970, 1971). In order to make APF independent of the choice of LIE theory, our calculations of APF have been carried out with $\Delta E^{(r)}$ values assumed as an *ad hoc* parameter with $0.01\,\text{eV} \leqslant \Delta E^{(r)} \leqslant 2.00\,\text{eV}$. The upper limit (2.00 eV) is chosen in order to accommodate results from Unsöld's formula (giving the highest LIE values) at $N_e = 10^{18}\,\text{cm}^{-3}$, whereas the lower limit (0.01 eV) may be useful if the concept of Debye screening (producing the lowest LIE values) is used with $N_e = 10^{12}\,\text{cm}^{-3}$ and $T = 40000$ K. Additional conditions on the lower limit of $\Delta E^{(r)}$ and on the upper limit of T are imposed by the fact that APF can be used effectively only if the iron abundances in the subsequent ionization states satisfy the inequalities $n^{(r)}/n^{(r+1)} \geqslant 0.03$ and $n^{(r+1)} \geqslant n^{(r+2)}$. Otherwise the r-th ionization state is negligible in the ionization balance of iron. Tables I, II and III list the numerical values of $U^{(r)}$ ($r = 1, 2, 3$), for a wide range of the physical conditions. These include every case where a given ionization state contributes more than 1 % of the atoms (or ions) to the total number of iron atoms and ions in the medium.

3. Results and conclusions.

Our numerical values of APF for iron are never smaller than the D-F values taken at the same T and LIE, whereas

the ratio $U^{(r+1)}/U^{(r)}$ is never greater than the corresponding D-F value. This is shown, as an example, on the right-hand side of figure 2 (c-d). The inequalities

$$U^{(r)}(T, \Delta E^{(r)}) > U_{D-F}^{(r)}(T, \Delta E^{(r)})$$

and

$$U^{(r+1)}(T, \Delta E^{(r+1)})/U^{(r)}(T, \Delta E^{(r)}) <$$
$$< U_{D-F}^{(r+1)}(T, \Delta E^{(r+1)})/U_{D-F}^{(r)}(T, \Delta E^{(r)})$$

become more pronounced when T increases (at $\Delta E^{(r)}$ = const.) or when $\Delta E^{(r)}$ decreases (at T = const.). The left-hand side of figure 2 (a-b) illustrates the variation of $U^{(1)}$ and of $U^{(2)}/U^{(1)}$ values *versus* LIE values for some values of T as a constant parameter. In the region of high T and of small N_e (corresponding to small LIE-values), i.e., in the conditions which we meet most frequently in astrophysics, the slope of the curves is greatest. So a numerical APF value which we take from the tables for a given physical condition in this region, is especially dependent on the LIE theory which we use.

Take typical conditions of a laboratory plasma, $N_e = 3 \times 10^{16}\,\text{cm}^{-3}$ and $T = 10^4$ K. If we infer the concentration of neutral iron, $n^{(1)}$, from the Boltzmann law and from the measured emission coefficient of a spectral line using our APF values and, alternatively, D-F values, we obtain a ratio $n^{(1)}/n_{D-F}^{(1)} = 1.86$ when Debye's $\Delta E^{(1)}$-value is used, or 1.26 when value of $\Delta E^{(1)}$ is taken according to Unsöld's theory. Employing the Saha law we have $\left(\dfrac{n^{(2)}}{n^{(1)}}\right) \Big/ \left(\dfrac{n^{(2)}}{n^{(1)}}\right)_{D-F} = 0.53$ or 0.79, respectively, for the same LIE-values as above. We note that under the assumed physical conditions, one gets $n^{(2)}/n^{(1)} = 5.5$, i.e. the share of neutral iron in the ionization balance of iron is still in no way negligible.

In an earlier phase of our calculations the data $E_{pi}^{(r)}$ and $g_{pi}^{(r)}$ were taken from the experimental R-S table; further $E_{pi}^{(r)}$-values have been calculated using the approximation methods of quantum mechanics. For FeII and FeIV some additional measurements have become accessible (numerous new levels in E-E and J papers by the Lund group. We have carried out the APF calculations anew combining the R-S and the Lund group data. We can note that these APF-values (published here) differ insignificantly from our earlier results. At high temperatures $U^{(4)}$-values are greater at most by 0.5 %, and $U^{(2)}$-values are smaller at most by 2.0 %. We take this as an endorsement for the approximation methods of $E_{pi}^{(r)}$-value determination for APF-calculations.

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TABLE I. — *The atomic partition functions for* FeI.

T [K]	Lowering of the ionization energy [eV]											
	0.01		0.05		0.10		0.25		0.50		1.00	
2000	.1992"	2	.1992"	2	.1992"	2	.1992"	2	.1992"	2	.1992"	2
3000	.2302"	2	.2302"	2	.2302"	2	.2302"	2	.2302"	2	.2302"	2
4000	.2631"	2	.2631"	2	.2631"	2	.2631"	2	.2631"	2	.2631"	2
5000	.3021"	2	.3019"	2	.3019"	2	.3019"	2	.3019"	2	.3019"	2
5500	.3255"	2	.3247"	2	.3246"	2	.3245"	2	.3245"	2	.3245"	2
6000	.3541"	2	.3507"	2	.3501"	2	.3499"	2	.3498"	2	.3497"	2
6500	.3928"	2	.3812"	2	.3793"	2	.3785"	2	.3783"	2	.3781"	2
7000	.4516"	2	.4186"	2	.4132"	2	.4110"	2	.4103"	2	.4099"	2
7500	.5493"	2	.4669"	2	.4536"	2	.4481"	2	.4465"	2	.4456"	2
8000	.7168"	2	.5324"	2	.5028"	2	.4907"	2	.4873"	2	.4854"	2
8500	.1002"	3	.6246"	2	.5645"	2	.5401"	2	.5334"	2	.5298"	2
9000	.1473"	3	.7570"	2	.6436"	2	.5979"	2	.5855"	2	.5791"	2
9500	.2225"	3	.9474"	2	.7465"	2	.6660"	2	.6445"	2	.6336"	2
10000	.3378"	3	.1219"	3	.8814"	2	.7469"	2	.7114"	2	.6938"	2
10500	.5087"	3	.1600"	3	.1058"	3	.8433"	2	.7871"	2	.7601"	2
11000	.7545"	3	.2125"	3	.1289"	3	.9587"	2	.8731"	2	.8328"	2
11500	.1099"	4	.2835"	3	.1588"	3	.1097"	3	.9707"	2	.9124"	2
12000	.1571"	4	.3776"	3	.1970"	3	.1262"	3	.1081"	3	.9995"	2
12500	.2212"	4	.5004"	3	.2455"	3	.1459"	3	.1207"	3	.1094"	3
13000	.3074"	4	.6579"	3	.3061"	3	.1692"	3	.1349"	3	.1198"	3
13500	.4239"	4	.8575"	3	.3812"	3	.1968"	3	.1509"	3	.1310"	3
14000	.5828"	4	.1108"	4	.4734"	3	.2293"	3	.1689"	3	.1432"	3
14500	.8030"	4	.1419"	4	.5856"	3	.2674"	3	.1893"	3	.1564"	3
15000	.1114"	5	.1804"	4	.7212"	3	.3117"	3	.2120"	3	.1706"	3
16000	.2212"	5	.2869"	4	.1079"	4	.4225"	3	.2661"	3	.2026"	3
17000	.4584"	5	.4506"	4	.1591"	4	.5696"	3	.3333"	3	.2398"	3
18000	.9696"	5	.7077"	4	.2325"	4	.7629"	3	.4165"	3	.2830"	3
19000	.2037"	6	.1120"	5	.3383"	4	.1016"	4	.5189"	3	.3329"	3
20000	.4166"	6	.1793"	5	.4932"	4	.1346"	4	.6447"	3	.3907"	3
21000	.8220"	6	.2892"	5	.7221"	4	.1779"	4	.7994"	3	.4576"	3
22000	.1564"	7	.4673"	5	.1062"	5	.2347"	4	.9897"	3	.5352"	3

TABLE II. — *The atomic partition functions for* FeII.

T [K]	Lowering of the ionization energy [eV]											
	0.01		0.05		0.10		0.25		0.50		1.00	
2000	.2816"	2	.2816"	2	.2816"	2	.2816"	2	.2816"	2	.2816"	2
5000	.4340"	2	.4340"	2	.4340"	2	.4340"	2	.4340"	2	.4340"	2
8000	.5649"	2	.5649"	2	.5649"	2	.5649"	2	.5649"	2	.5649"	2
9000	.6153"	2	.6153"	2	.6153"	2	.6153"	2	.6153"	2	.6153"	2
10000	.6705"	2	.6701"	2	.6701"	2	.6701"	2	.6701"	2	.6701"	2
10500	.7004"	2	.6993"	2	.6992"	2	.6992"	2	.6992"	2	.6992"	2
11000	.7323"	2	.7298"	2	.7296"	2	.7295"	2	.7295"	2	.7295"	2
11500	.7671"	2	.7616"	2	.7612"	2	.7610"	2	.7610"	2	.7609"	2
12000	.8061"	2	.7949"	2	.7941"	2	.7937"	2	.7937"	2	.7936"	2
12500	.8518"	2	.8299"	2	.8285"	2	.8278"	2	.8276"	2	.8275"	2
13000	.9075"	2	.8671"	2	.8644"	2	.8631"	2	.8628"	2	.8627"	2
13500	.9785"	2	.9069"	2	.9022"	2	.8999"	2	.8994"	2	.8991"	2
14000	.1072"	3	.9501"	2	.9421"	2	.9382"	2	.9373"	2	.9369"	2
14500	.1198"	3	.9977"	2	.9847"	2	.9782"	2	.9767"	2	.9760"	2
15000	.1371"	3	.1051"	3	.1030"	3	.1020"	3	.1018"	3	.1017"	3
16000	.1931"	3	.1182"	3	.1134"	3	.1110"	3	.1105"	3	.1103"	3
17000	.2961"	3	.1364"	3	.1262"	3	.1212"	3	.1201"	3	.1196"	3
18000	.4773"	3	.1627"	3	.1426"	3	.1328"	3	.1307"	3	.1297"	3
19000	.7822"	3	.2012"	3	.1644"	3	.1464"	3	.1426"	3	.1408"	3
20000	.1273"	4	.2577"	3	.1938"	3	.1627"	3	.1561"	3	.1530"	3
21000	.2037"	4	.3395"	3	.2338"	3	.1825"	3	.1716"	3	.1665"	3
22000	.3196"	4	.4561"	3	.2880"	3	.2067"	3	.1895"	3	.1816"	3
23000	.4942"	4	.6191"	3	.3609"	3	.2366"	3	.2105"	3	.1986"	3
24000	.7591"	4	.8436"	3	.4580"	3	.2737"	3	.2351"	3	.2177"	3
25000	.1171"	5	.1149"	4	.5859"	3	.3195"	3	.2642"	3	.2392"	3
26000	.1836"	5	.1561"	4	.7527"	3	.3761"	3	.2984"	3	.2637"	3
27000	.2945"	5	.2116"	4	.9686"	3	.4457"	3	.3388"	3	.2914"	3
28000	.4847"	5	.2869"	4	.1247"	4	.5311"	3	.3864"	3	.3229"	3
29000	.8148"	5	.3900"	4	.1606"	4	.6355"	3	.4426"	3	.3588"	3
30000	.1387"	6	.5330"	4	.2069"	4	.7629"	3	.5086"	3	.3995"	3
31000	.2367"	6	.7342"	4	.2670"	4	.9185"	3	.5862"	3	.4458"	3
32000	.4022"	6	.1021"	5	.3455"	4	.1108"	4	.6774"	3	.4984"	3
33000	.6764"	6	.1434"	5	.4491"	4	.1341"	4	.7844"	3	.5583"	3
34000	.1124"	7	.2030"	5	.5868"	4	.1626"	4	.9101"	3	.6264"	3
35000	.1842"	7	.2892"	5	.7709"	4	.1977"	4	.1058"	4	.7040"	3
36000	.2986"	7	.4134"	5	.1018"	5	.2410"	4	.1232"	4	.7923"	3
37000	.4800"	7	.5916"	5	.1351"	5	.2949"	4	.1437"	4	.8929"	3

TABLE III. — *The atomic partition functions for* FeIII.

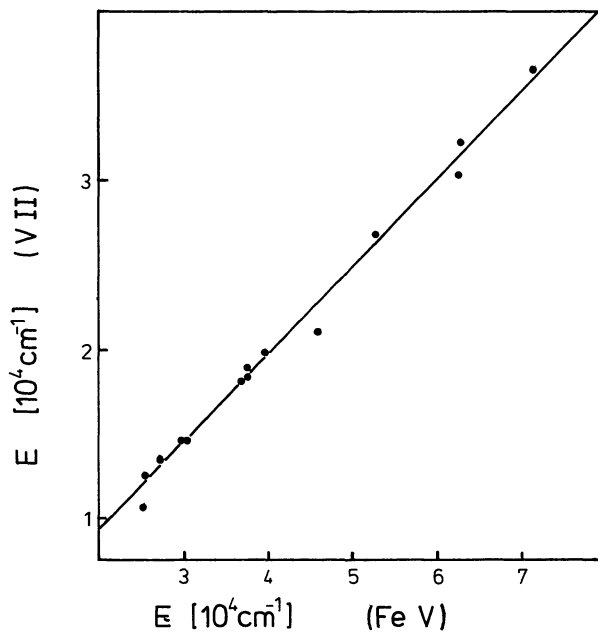| T [K]	Lowering of the ionization energy [eV]					
	0.05	0.10	0.25	0.50	1.00	2.00
2000	.1906" 2	.1906" 2	.1906" 2	.1906" 2	.1906" 2	.1906" 2
8000	.2531" 2	.2531" 2	.2531" 2	.2531" 2	.2531" 2	.2531" 2
12000	.3208" 2	.3208" 2	.3208" 2	.3208" 2	.3208" 2	.3208" 2
14000	.3652" 2	.3652" 2	.3652" 2	.3652" 2	.3652" 2	.3652" 2
15000	.3895" 2	.3895" 2	.3895" 2	.3895" 2	.3895" 2	.3895" 2
16000	.4149" 2	.4149" 2	.4149" 2	.4149" 2	.4149" 2	.4149" 2
16500	.4280" 2	.4280" 2	.4280" 2	.4280" 2	.4280" 2	.4280" 2
17000	.4414" 2	.4414" 2	.4414" 2	.4414" 2	.4414" 2	.4414" 2
17500	.4551" 2	.4551" 2	.4551" 2	.4551" 2	.4551" 2	.4551" 2
18000	.4690" 2	.4690" 2	.4690" 2	.4690" 2	.4690" 2	.4690" 2
18500	.4832" 2	.4832" 2	.4832" 2	.4832" 2	.4832" 2	.4832" 2
19000	.4977" 2	.4976" 2	.4976" 2	.4976" 2	.4976" 2	.4976" 2
19500	.5124" 2	.5123" 2	.5123" 2	.5123" 2	.5123" 2	.5123" 2
20000	.5275" 2	.5273" 2	.5272" 2	.5272" 2	.5272" 2	.5272" 2
21000	.5585" 2	.5581" 2	.5579" 2	.5579" 2	.5579" 2	.5578" 2
22000	.5911" 2	.5901" 2	.5897" 2	.5896" 2	.5896" 2	.5895" 2
23000	.6258" 2	.6236" 2	.6228" 2	.6225" 2	.6224" 2	.6224" 2
24000	.6633" 2	.6589" 2	.6571" 2	.6567" 2	.6565" 2	.6564" 2
25000	.7050" 2	.6964" 2	.6931" 2	.6922" 2	.6919" 2	.6917" 2
26000	.7530" 2	.7371" 2	.7309" 2	.7292" 2	.7286" 2	.7283" 2
27000	.8102" 2	.7819" 2	.7710" 2	.7680" 2	.7670" 2	.7663" 2
28000	.8807" 2	.8324" 2	.8139" 2	.8088" 2	.8070" 2	.8060" 2
29000	.9703" 2	.8908" 2	.8603" 2	.8519" 2	.8491" 2	.8473" 2
30000	.1087" 3	.9597" 2	.9112" 2	.8978" 2	.8933" 2	.8905" 2
31000	.1240" 3	.1043" 3	.9676" 2	.9469" 2	.9401" 2	.9358" 2
32000	.1442" 3	.1145" 3	.1031" 3	.1000" 3	.9897" 2	.9834" 2
33000	.1709" 3	.1271" 3	.1104" 3	.1058" 3	.1043" 3	.1033" 3
34000	.2062" 3	.1428" 3	.1187" 3	.1121" 3	.1099" 3	.1086" 3
35000	.2523" 3	.1625" 3	.1284" 3	.1191" 3	.1160" 3	.1142" 3
36000	.3124" 3	.1871" 3	.1397" 3	.1268" 3	.1226" 3	.1201" 3
37000	.3899" 3	.2179" 3	.1531" 3	.1355" 3	.1298" 3	.1264" 3
38000	.4894" 3	.2563" 3	.1689" 3	.1453" 3	.1376" 3	.1331" 3
39000	.6164" 3	.3039" 3	.1876" 3	.1563" 3	.1462" 3	.1403" 3
40000	.7780" 3	.3638" 3	.2097" 3	.1687" 3	.1556" 3	.1479" 3

FIGURE 1. — The excitation energies for terms of FeV plotted against corresponding quantities of VII.
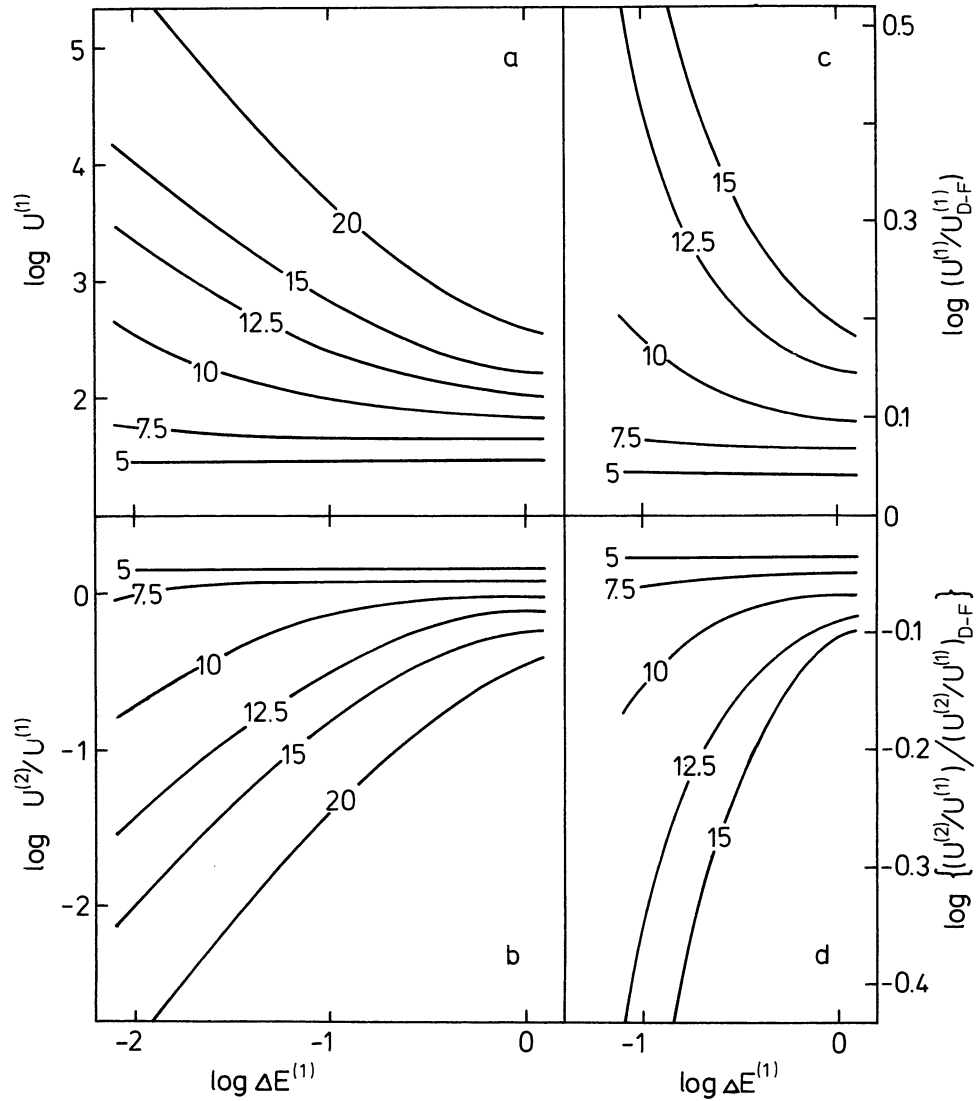
FIGURE 2. — Partition functions for iron *versus* FeI lowering of ionization energy. For explanation see text. The curves are plotted in the logarithmic APF and $\Delta E^{(1)}$ scales, at constant value of temperature as a parameter. The Unsöld relation $\Delta E^{(2)} = 2^{2/3} \Delta E^{(1)}$ is used.