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Abstract

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Yu. I. Ostrovskii, N. P. Penkin, and L. N. Shabanova

Absolute Values of Oscillator Strengths of the Resonance Lines of MgI, CaI, SrI, and BaI

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The measurement of absolute values of oscillator strengths (the numbers f) by existing optical methods is usually associated with the need to determine the concentration of the emitting or absorbing atoms. In those cases where the vapor column under study is produced in a glass or quartz cuvette (absorption methods or Rozhdestvenskii hooks), the concentration of absorbing atoms is calculated from formulas giving the dependence of saturated-vapor pressure on temperature. It is thereby assumed that the vapor is in thermodynamic equilibrium with the condensate. Such an assumption is valid if there is no active chemical interaction of the vapor with the walls of the cuvette. For many elements, for example for the alkaline earths, this assumption is not fulfilled; for them it is impossible to create a vapor column of a strictly defined length and temperature with a known concentration of absorbing atoms. In such cases the hook and absorption methods in their usual form prove inapplicable for determining the absolute numbers f of the spectral lines of these elements.

In an apparatus used for measuring absolute oscillator strengths by the hook (or absorption) method, it is not possible to obtain a vapor column at temperatures higher than 1200°, which greatly limits the number of elements that can be studied by this reliable method.

It should also be noted that the low accuracy of vapor-pressure equations is often the principal source of errors arising in the measurement of absolute values of oscillator strengths.

To eliminate the difficulties listed above, we have applied a new method for determining absolute oscillator strengths, based on the simultaneous measurement of total absorption and dispersion. In the proposed method there is no need to create a vapor column with a known and constant concentration of absorbing atoms.

As is known, the hook method makes it possible to determine the product $N_i f_{ik}$, if the distance Δ_{ik} between the vertices of the hooks has been measured. The theory of this method (^{1}) leads to the formula

$$N_i f_{ik} = \frac{\pi m c^2 K_{ik}}{e^2 d \lambda_{ik}^3} \Delta_{ik}^2.$$

Here e and m are the charge and mass of the electron; c is the speed of light; λ_{ik} is the wavelength of the absorption line; d is the length of the vapor column; K_{ik} is the hook-method constant, determined by the thickness and refractive index of the plane-parallel plate inserted into the interferometer to form the hooks.

On the other hand, it is known that if the pressure of the absorbing vapor or gas is so small (10^{-2}—10^{-4} mm Hg) that Holtsmark broadening may be neglected, and $k_\nu d$ has a value equal to several thousand, then the form of the absorption line will be determined exclusively by its natural ⋯

pits (2). In this case the equivalent width of the absorption line A_λ is equal to

$$A_\lambda = \frac{\lambda_{ik}^2 e}{m^{1/2} c^{3/2}} \sqrt{N_i f_{ik} \gamma d}.$$

From the last two formulas we obtain for the damping coefficient

$$\gamma = \frac{c}{\pi K_{ik} \lambda_{ik}} \left(\frac{A_\lambda}{\Delta_{ik}} \right)^2.$$

Consequently, by measuring A_λ and Δ_{ik} under the same conditions, one can find the quantity γ, which is determined by the lifetimes of the upper and lower levels (τ_k, τ_i) and by the damping coefficient due to collisions (γ_{st})

$$\gamma = \frac{1}{\tau_k} + \frac{1}{\tau_i} + \gamma_{\mathrm{st}}.$$

For resonance lines, in the absence of radiation of high density and of quenching collisions $\left(\frac{1}{\tau_i} = 0;\ \gamma_{\mathrm{st}} = 0 \right)$, the quantity γ is equal to the probability of the spontaneous transition A_{ki}, which is uniquely related to the oscillator strength f_{ik}. It is evident that the given method will make it possible not only to measure the f values of absorption lines for a large number of elements, including those that are difficult to evaporate, but will also make it possible to determine the effective cross sections of atoms and molecules for quenching collisions.

Table 1

Elements	λ, Å	f (lit.)	f (lit.)	f_{theor}
Mg	2852	1.2 ± 0.3	–	1.674 (7)
Ca	4227	1.3 ± 0.2	2.3 (10)	1.458 (9)

Fig. 1. Dependence of the f values of the resonance lines of alkaline-earth atoms on the atomic number Z.

Figure 1: Fig. 1. Dependence of the f values of the resonance lines of alkaline-earth atoms on the atomic number Z.

Elements	λ, Å	f (lit.)	f (lit.)	f_{theor}
Sr	4607	1.5 ± 0.2	–	–
Ba	5535	1.7 ± 0.2	1.8 (^{11})	–

For verification of the method we measured the f value of the line $^2p_{1/2} - {}^2s_{1/2}$ ($\lambda = 4102\,\text{Å}$) of InI; it was found to be 0.20, which is in good agreement with the results of measurements by the hook method (^{3}).

Fig. 1. Dependence of the f values of the resonance lines of alkaline-earth atoms on the atomic number Z.

It should be pointed out that a method analogous to that described, but based on simultaneous measurement of absorption and magnetic rotation, was used by Minkowski (^{4}), Schütz (^{5}), and Vengerov (^{6}).

By the indicated method we determined the absolute values of the f numbers of the resonance lines ($^1p_1 - {}^1s_0$) of MgI, CaI, SrI, and BaI. The optical part of the experimental apparatus that we used is analogous to that described in (^{7}). A column of the vapor under investigation was formed in an evacuated quartz tube by a diffusion pump, inside which an iron tube was inserted, protecting the quartz from interaction with the metal and its vapors. The magnitude of the total absorption was measured by photographic photometry; a registering microphotometer MF-4 was used.

The results of our measurements and the data of other authors are given in Table 1.

The accuracy of the f values obtained by the method of simultaneous measurement of absorption and dispersion is not high, but it can be improved if photoelectric methods are used for recording the total absorption.

There are several works in which the oscillator strengths of the resonance lines of Mg and Ca have been calculated by approximate methods of quantum mechanics. In Table 1 we have included only the result of Trefft' s calculations, which,

from our point of view, are the most accurate. From a comparison of the data given in the table it follows that: 1) for the Ba atom, our results agree well with Wessel' s data, obtained by the absorption method in an atomic beam; 2) for the resonance line of Ca, our value of f agrees well with the value of f calculated by Trefftz, and differs greatly from that measured by Steinhäuser. We are inclined to attribute this discrepancy to errors in Steinhäuser' s work, which was carried out by the not very accurate method of measuring the depolarization of resonance fluorescence in a magnetic field.

Figure 1 shows the dependence of the values of f measured by us on the ordinal number of the element Z. It is evident that the values of f increase linearly with increasing Z.

Leningrad State University
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