Isotope shifts in $\lambda 326.1$ nm of CdI

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We have measured isotope shifts in $\lambda 326.1$ nm of CdI using a pressure-scanned interferometer. The results are, in GHz: $116 - 106$, $-2.222(30)$; $113 - 108$, $-1.052(10)$; $111 - 110$, $-0.049(12)$; $111 - 106$, $-1.048(10)$. Results for stable isotopes in $\lambda 326.1$ nm are needed in the interpretation of existing measurements on radioactive cadmium isotopes. The new data are more precise than early atomic beam measurements but are reasonably consistent with them.

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We report measurements of shifts between stable isotopes in the intercombination line $\lambda 326.1$ nm in the atomic spectrum of cadmium, $4d^{10} 5s^2 \, ^1S_0 - 4d^{10} 5s \, 5p \, ^3P_1$. They were undertaken to complement work on radioactive isotopes in the same transition by Buchinger et al. [1, 2]. Reliable data for the stable isotopes in $\lambda 326.1$ nm are important for the following reason. A major problem in extracting nuclear information from measurements in $\lambda 326.1$ nm is that the observed shifts depend on electronic factors associated with the transition which cannot be calculated to sufficient accuracy. The normal method of dealing with this problem is to combine the results with shift measurements in another line for which the electronic factors can be estimated more reliably. The approach has also been used in $\lambda 226.5$ nm [6], giving results in poor agreement with the later emission experiments [3]. It therefore appeared worthwhile to carry out new experiments in $\lambda 326.1$ nm to ensure that the best use could be made of the measurements in radioactive isotopes. In the following we first give the necessary background, then describe the experiment and finally discuss the results.

Following the notation and sign convention of [4] we write the following expression for an isotope shift $\delta v_{j, A'A}$ in a spectral line $j$ of cadmium:

$$\delta v_{j, A'A} = F_j f(Z) A_{AA'} + M_j g(a, a').$$

We take $j=1, 2$ to refer to $\lambda 326.1, 226.5$ nm respectively. The two terms in (1) represent respectively the “field” and “mass” contributions to the shift. $A, A'$ are the mass numbers of the isotope pair and $a, a'$ are the corresponding nuclear masses. The most comprehensive set of measurements available in $\lambda 326.1$ nm is that of Kelly and Tomchuk [5]; this work was carried out photographically using an atomic beam containing the natural mixture of isotopes. The approach has also been used in $\lambda 226.5$ nm [6], giving results in poor agreement with the later emission experiments [3]. It therefore appeared worthwhile to carry out new experiments in $\lambda 326.1$ nm to ensure that the best use could be made of the measurements in radioactive isotopes. In the following we first give the necessary background, then describe the experiment and finally discuss the results.

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$$g(a, a') = \frac{a - a'}{a(112) - a(110)} \frac{a(112) \cdot a(110)}{a \cdot a'}.$$
$A_{AA}$ is the nuclear quantity of interest; it can be expressed as a series of charge moments [7, 8], the leading term being $\delta \langle r^2 \rangle_{AA}$.

Thus, in order to find values of $A_{AA}$ from measured isotope shifts in $\lambda 326.1$ nm one must evaluate the electronic factors $F_1$ and $M_1$. $F_1$ is proportional to the difference in the probability density of the electrons within the nucleus from one level of the transition to the other, while $M_1$ involves the cross-products of the momenta of all the electrons in the atom. $F_1$ and $M_1$ can be evaluated from $F_2$ and $M_2$ using the method given by King [9], as follows.

From (1) we have

$$\delta v_{1,AA} = \frac{F_1}{F_2} \delta v_{2,AA} + (M_1 - \frac{F_1}{F_2} M_2) g(a, a').$$

(3)

Thus, provided that results for at least two common isotope pairs exist in both lines the measurements allow one to determine the King parameters

$$\rho_{12} = \frac{F_1}{F_2}, \quad \mu_{12} = M_1 - \rho_{12} M_2.$$  \hspace{1cm} (4)

From [3] we have the relative positions of all the stable isotopes in $\lambda 226.5$ nm; it was therefore necessary to measure at least two such shifts in $\lambda 326.1$ nm.

The general method was similar to that described in [3]. The cadmium spectrum was excited in a hollow cathode discharge cooled with liquid nitrogen and run at a current of 2–3 mA. Neon was the carrier gas. High resolution was achieved by means of a pressure scanned Fabry-Perot interferometer used in conjunction with a grating monochromator. Despite the linewidth of over 1 GHz, it was possible to carry out the work with mixtures of enriched isotopic samples in the sources. The three odd-even mixtures studied gave resolved components because of the large hyperfine structure (see Fig. 1) while the shift between $^{116}$Cd and $^{106}$Cd was large enough to be measured directly. The spectrum of the natural mixture of isotopes was also studied. Some 20–30 orders of interference were recorded from each source with each of two etalon spacings; the data processing and fitting were carried out by computer. We note that the experiment has much in common with the work of Leš [10] on $\lambda 326.1$ nm, but with the advantages of more highly enriched samples, photo-electric recording and modern data-processing techniques.

Interferograms of a sample enriched in $^{111}$Cd were recorded separately to allow the hyperfine structure to be measured. The splitting was found to be consistent with the much more precise value given by optical double resonance [11]. The ODR method gives the separations of the hyperfine components to be 6.186 GHz ($^{111}$Cd) and 6.471 GHz ($^{113}$Cd); we adopted these values in the analyses of the mixtures.

A sample enriched in $^{106}$Cd was also studied separately in order to investigate the line profile. As in our earlier experiments [3] the profile was slightly asymmetrical. The need to describe it by four largely empirical parameters (e.g., Lorentzian width, Gaussian width, and two to specify the asymmetry) leads to uncertainty in the analysis which was the main source of error in the work.

The results are given in Table 1; Figure 2 shows a King plot of measurements in $\lambda 326.1$ nm against those in $\lambda 226.5$ nm, i.e. a plot of $\delta v_{1,AA}/g(a, a')$ vs. $\delta v_{2,AA}/g(a, a')$. The figure includes the early measurements in $\lambda 326.1$ nm [5]; this is the most convenient way of comparing them with the new data since there is incomplete overlap between the isotopes measured in the two experiments. However, the line drawn is the best fit to the new measurements only. The King parameters (Eq. (4) above) are obtained from the slope.

![Fig. 1](image-url)