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Photoabsorption cross section of barium from 237.9 to 120 nm

E. B. Saloman
Center for Radiation Research, National Bureau of Standards,
Gaithersburg, Maryland 20899

J. W. Cooper
Center for Basic Standards, National Bureau of Standards,
Gaithersburg, Maryland 20899

G. Mehlman*
Center for Radiation Research, National Bureau of Standards,
Gaithersburg, Maryland 20899

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The relative photoabsorption cross section of barium in the spectral range from the ionization limit at 237.9 to 120 nm has been measured and the results of previous measurements extending to 170 nm confirmed. The cross section is found to rise slowly at wavelengths shorter than 170 nm and to decrease in the region between 140 and 130 nm.

The absorption cross section of barium in the region above the ionization limit at 237.9 nm is extremely complex. Two electron transitions from the $6s^2\,{}^1S_0$ ground state are quite likely to occur, owing to strong configuration-interaction effects, and this results in a complex series of autoionizing resonances converging to the $5d\,{}^2D_{3/2,\,5/2}$ limits at 213.18 and 209.60 nm and the $6p\,{}^2P_{1/2,\,3/2}$ limits at 160.52 and 156.28 nm. While these resonances have been carefully studied by spectroscopic techniques,[1–4] there has been only one measurement of the total cross section in this region. This note describes a remeasurement of the relative cross section over the range considered in Ref. 5 (237.90–170 nm) and an extension of the measurements to shorter wavelengths.

The light source used for these measurements was the National Bureau of Standards (NBS) storage ring SURF-II (Synchrotron Ultraviolet Radiation Facility, Gaithersburg, MD). Synchrotron radiation from the ring was focused on the entrance slit of a 0.2 m monochromator by a 30-cm-long mirror which provided focusing in both the vertical and horizontal directions. The bandpass of the monochromator was 0.2 nm and was achieved with a grating of 1200 lines/mm and a 50-μm exit slit. Light from the exit slit of the monochromator passed through a barium heat pipe 13-cm long and was detected with a photomultiplier mounted at the exit window of the heat pipe. MgF_2 windows were used, which meant that measurements could only be made at wavelengths longer than 120 nm.

The heat pipe used here was designed specifically to provide a stable column density.[6] It consisted of a large cylindrical chamber, 13 cm in diameter and 35 cm high, containing lithium vapor. The barium-vapor cell was a 1-in. (2.54 cm) tube mounted within the heating chamber at right angles to its axis. Argon was used as a buffer gas in both the lithium chamber and the barium-vapor cell. A stable column density was achieved by heating the lithium vapor to the point where appreciable absorption occurred in the barium cell and then maintaining a constant pressure of buffer gas in the lithium chamber. Stability was also monitored via thermocouples on the outside of both chambers. Typical operating temperatures were in the 1000–1100 °C range with buffer gas pressures of 35–40 Torr in the lithium chamber and 1–10 Torr in the barium-vapor cell.

Data were obtained by sweeping the monochromator over a given spectral range and monitoring transmitted flux at 0.1- or 0.5-nm intervals. Typical count times with the monochromator stopped at a given wavelength were 1–2 sec. In order to obtain an estimate of the transmitted flux with no barium vapor present in the cell, special precautions had to be taken due to small amounts of impurities. The procedure was to heat the apparatus to a point where no absorption was detected at the wavelength where the barium cross section has its maximum value (~237.9 nm), and to obtain a measure of the incident flux under these operating conditions at all wavelengths. The vapor pressure was then increased and absorption data taken. Finally, the apparatus was cooled down to a temperature below which barium absorption could be detected and another spectral scan was taken.

While Ref. 5 represents extremely careful work, there is

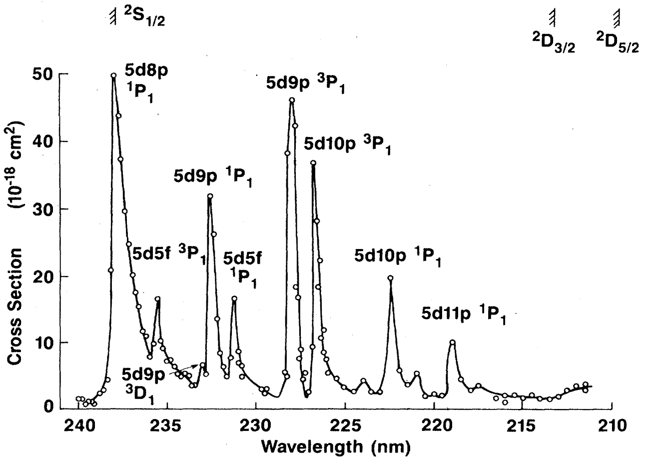

FIG. 1. The barium photoabsorption cross section (in megabarns) from threshold (at 237.9 nm) to 210 nm.

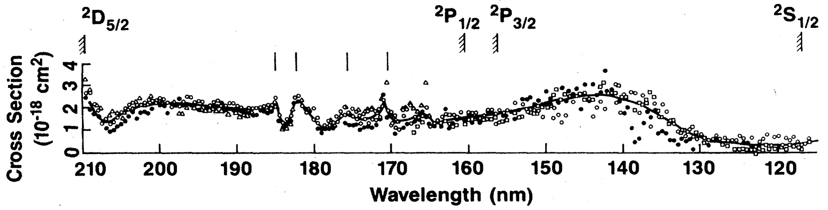

FIG. 2. The barium photoabsorption cross section (in megabarns) from 210 to 120 nm. The positions of the four absorption peaks between 190 and 170 nm from Ref. 5 are indicated in the figure.

evidence that the absolute magnitudes of the cross sections reported there are too small, presumably due to inaccuracies in the vapor-pressure data used to obtain the absolute cross sections. Carlsten and McIlrath[7] determined the cross section at the threshold absorption peak at 237.9 nm by measuring the ratio of the absorption relative to that of the $6s^2$-$6s7p$ resonance line. Their value of $50 \pm 8 \times 10^{-18}$ cm^2 is approximately five times larger than that of Ref. 5. Driver[8] measured the ratio of the cross sections at 40.5 nm relative to that at 237.9 nm and found that using the value of Ref. 5 yielded a value of the cross section at 40.5 nm, which was three times smaller than theoretical predictions.[9] More recently, Armstrong and Wynne[10] have extrapolated the available data on oscillator strengths in the discrete region[11] using multichannel quantum-defect theory to obtain a value of the cross section at 237.9 nm of 56×10^{-18} cm^2, in close agreement with the results of Ref. 7. In view of the above considerations, we have normalized our data to the threshold values of Ref. 7. The results are shown for the region from threshold to the $5d\,^2D_{5/2}$ ionization limit at 209.6 nm in Fig. 1 and in the region from this limit to 120 nm in Fig. 2.

Apart from the difference in normalization, the data shown in Fig. 1 are in good agreement with that of Ref. 5. Since our measurements were made at low resolution, the detailed resonance structure between 225 and 209.6 nm is not resolved. However, all of the major peaks at longer wavelengths are present and are consistent with the results of Ref. 5.

The results shown in Fig. 2 are also consistent with previous work,[4,5] apart from normalization. In the wavelength region between 210 and 170 nm all of the broad features previously reported appear in our data. However, with the exception of the peak at 171 nm, we cannot resolve any of the complex structure which is present below the $^2P_{3/2}$ limit and has been studied spectroscopically at high resolution.[4]

The new result of our work is the extension of the average cross section to wavelengths shorter than 170 nm. As shown in Fig. 2, the cross section rises slowly above the $^2P_{3/2}$ limit and falls off to near-zero values in the region between 140 and 130 nm. Although, as seen in Fig. 2, there is a good deal of scatter in the results at wavelengths below 130 nm, we conclude that the cross section between 130 and 120 nm is less than 0.5×10^{-18} cm^2.

It should be mentioned that the results reported here represent only a minor fraction of the total oscillator strength for transitions from the $^1S_0$ ground state. The bulk of the oscillator-strength distribution is due to transitions to the $6s6p\,^1P_1$ and $6s7p\,^1P_1$ states which have oscillator strengths of 1.59 and 0.17, respectively.[11] In contrast to this, a summation over the absorption f values reported in Ref. 5 in the energy region below the $5d\,^2D_{5/2}$ limit multiplied by a factor of 5 to account for the renormalization of the cross section yields an integrated strength of only 0.028, and an integration of the data reported here from 210 to 130 nm yields an integrated oscillator strength of 0.04.

Finally, our work suggests that further experiments in this spectral region would be desirable. It would be interesting to obtain high-resolution spectra in the region below 150 nm to see if there are resonances converging to the $7s\,^2S_{1/2}$ limit of Ba$^+$ at 118.5 nm or to higher limits. It would also be important to make a new determination of the absolute cross section in this spectral range in order to resolve the discrepancy between Ref. 5 and more recent work.

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*Present address: Naval Research Laboratory, Washington, DC 20375.

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