Cross sections and characteristics of electron scattering by calcium, strontium, and barium atoms

N. I. Romanyuk, O. B. Shpenik, and I. P. Zapesochnyĭ
Uzhgorod State University

(Submitted 19 August 1980)
Pis'ma Zh. Eksp. Teor. Fiz. **32**, No. 7, 472–475 (5 October 1980)

The total cross sections for scattering of electrons by calcium, strontium, and barium atoms were determined for the first time in the energy region 0.1–10 eV, using a modified electron-trap method and atomic-beam modulation.

PACS numbers: 34.80. – i

Until now, the experimental data for the total effective cross sections for scattering of electrons by atoms of the alkali-earth elements have not been available, except for magnesium and barium for which Trajmar's group[1,2] determined the integral elastic and inelastic scattering cross sections at several energies in the region 10–40 eV. At the same time, the experimental data for the effective scattering cross sections are urgently needed for testing various theoretical models, especially at low energies (below 10 eV), and also for several practical needs, since these elements have recently found wide application as the active media of lasers and in artificial plasma formation in the upper atmospheric layers. As a result, we have developed a method of determining the total cross sections for scattering of electrons by atoms, which makes it possible to perform an investigation beginning with an energy of 0.1 eV. We report in this paper the first results of investigations of the total cross sections for scattering of electrons by Ca, Sr, and Ba atoms, using highly uniform electron beams.

The experiments were performed in intersecting, monoenergetic, electron and modulated atomic beams using a synchronous signal storage. To detect the scattered electrons, we used a modified electron-trap method, in which a collision chamber was used as a collector of scattered electrons, and the entire electron-optical system was placed in a longitudinal magnetic field needed for velocity selection of the electrons in the trochoidal electron monochromator and for collimation of the electron beam. The electrodes, whose potentials are close to the cathode potential, were mounted at the entrance to the collision chamber and at its exit. This formed a trap for the electrons that lose some of their energy due to excitation or change their direction as a result of collision with an atom. The scattered electrons oscillate between these electrodes along the magnetic field until they settle in the collision chamber. Thus, the measurement of the total scattering cross section reduces to detection of the total current of the scattered electrons, rather than a determination of the attenuation of the primary electron beam that passes through the target layer, as in the traditional experiments.[3] This is an important advantage of the proposed method, since the sensitivity of the measurements is increased in this case by approximately two orders of magnitude. Special measures were used to prevent the primary electron beam from striking the collision-chamber walls: alignment of the apertures of the electrodes; in addition, the diameters of the apertures in the electrodes increased along the electron path from 0.2 mm at the exit from the electron monochromator to 0.8 mm in the electrode at the exit of the collision chamber.

An atomic beam with a 12° divergence angle, which was formed by an effusion source, was modulated by a mechanical chopper with a 20-Hz frequency. The entire device was placed in a heated vacuum chamber that was evacuated by two NORD-100 electrodischarge pumps. The current of scattered electrons was recorded at the modulation frequency of the atomic beam. The recording system includes a pre-amplifier, a low-frequency filter, a selective amplifier, a voltage-to-frequency converter, a digital synchronous detector, and a reversible counter. Sweeping of the accelerating voltage was accomplished by a step-voltage generator that operated in the programmed mode. All the measured values (primary beam current, accelerating voltage, and scattering signal) were recorded by V2–20, V2–23, and F5007 digital instruments and displayed on a digital printer. Multiple scans (12–20 times) were made of the entire investigated energy range 1 (0–10 eV) in steps of 0.1–0.4 eV as well as of the specific portions of this range in steps of 0.02–0.04 eV for a more detailed study of the scattering curves.

The absolute scattering cross sections were determined by calibrating the recording system according to the ion current that was measured during electron-impact ionization of the atoms whose cross sections are known.[4] The error in determining the scattering cross sections, in which the error in determining the ionization cross sections was taken into account, is 38% for Ca, 32% for Sr, and 35% for Ba. This value does not include the error due to the angular resolution of the instrument, which amounted to 15° at 1 eV and 1° at 10 eV.

Using the described method, we have investigated for the first time the total cross

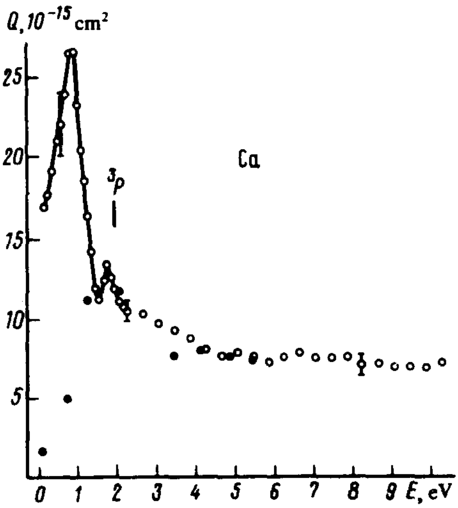

FIG. 1. Effective cross sections for scattering of electrons by calcium atoms: ○, experiment; ●, calculated data.[5]

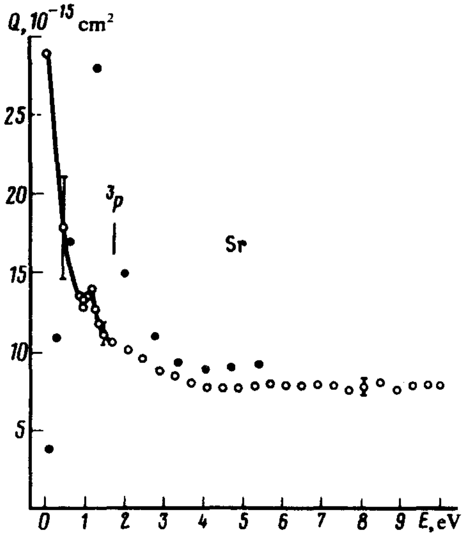

FIG. 2. Effective cross sections for scattering of electrons by strontium atoms: ○, experiment; ●, calculated data.[5]

sections for scattering of electrons by Ca, Sr, and Ba atoms in the energy interval from 0.1 to 10 eV for a total electron energy spread of 0.04–0.08 eV at the half-maximum of the distribution. The absolute scattering cross sections were also determined and the scattering cross sections were analyzed in detail. The results of the measurements and the data (solid circles) of Fabrikant's calculations[5] in the coupling approximation of the ^1S-^1P-^3P states for Ca and the ^1S-^1P-^1D states for Sr and Ba are shown in Figs. 1–3.

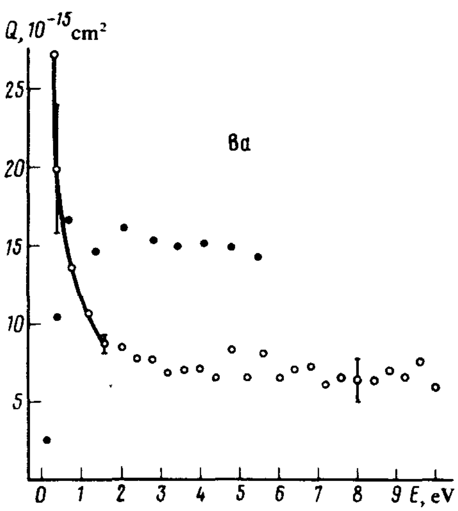

FIG. 3. Effective cross sections for scattering of electrons by barium atoms: ○, experiment; ●, calculated data.[5]

We can see from the given results that the largest discrepancy between the calculated results and the experimental data is observed at energies below the first excited state of the atom.

The energy dependences of the total of the cross sections for all atoms are characterized by a steep decrease of the cross section as the electron energy increases from 0.1 to 10 eV. Thus, the maximum cross section for Ca, which is equal to 26.5×10^{-15} cm^2 at 0.7 ± 0.1 eV, decreases to 7.4×10^{-15} cm^2 at 10 eV. The maximum at 0.7 eV is apparently caused by the formation and decay of the short-lived state of a negative ion $(4s^24p)^2P\,Ca^-$. The location of the secondary maximum at 1.7 eV is close to the 1.62-eV energy of the $(d\,^1s^2)^2D$ state of a negative calcium ion, which was determined by using the horizontal extrapolation method.[5]

The cross section for scattering of electrons by strontium atoms decreases steeply from 28.9×10^{-15} cm^2 at 0.1 eV to 7.7×10^{-15} cm^2 at 4 eV and then remains constant within the accuracy limits of the cross section. The cross section maximum at 1.2 ± 0.1 eV cannot be explained by the threshold effects, since it lies 0.6 eV below the first excited ^5P state of a strontium atom. As in the case of a Ca atom, it is attributable to the $(d\,^1s^2)^2D$ state of a negative strontium ion.

The energy dependence of the total cross section for scattering by barium atoms, which is characterized by the steepest decrease from 41.1×10^{-15} cm^2 at 0.2 eV to 6.9×10^{-15} cm^2 at 3.2 eV, remains practically constant within the accuracy limits of the measurements. A careful study of the region of the lowest ^3D, ^1D, and ^3P states of a barium atom showed no evidence of an abnormality of the effective cross section that falls outside the statistical spread of the measurements.

[1]W. Williams and S. Trajmar, J. Phys. B **11**, 2021 (1978).

[2]S. Jensen, D. Register, and S. Trajmar, J. Phys. B **11**, 2367 (1978).

[3]B. Bederson and L. J. Kieffer, Rev. Mod. Phys. **43**, 601 (1971).

[4]L. A. Vainshtein, V. I. Ochkur, V. I. Rakhovskiĭ, and A. M. Stepanov, Zh. Eksp. Teor. Fiz. **61**, 511 (1971) [Sov. Phys. JETP **34**, 271 (1972)].

[5]I. I. Fabrikant, Collisions of slow electrons with alkali-earth atoms. In: Atomnye protsessy (Atomic Processes), edited by R. K. Peterkop, Zinatne, Riga, 1975, p. 80.

[6]G. Massey, Negative Ions (Russ. Transl., Mir, Moscow, 1979).

Translated by Eugene R. Heath
Edited by S. J. Amoretty