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# Structure observed during detailed measurements of detachment from $H^-$ by electron impact

**Abstract.** Absolute cross sections for single detachment from $H^-$ by electron impact have been measured by an inclined beam technique. At interaction energies close to 14·5 eV the detachment function shows structure which is attributed to the formation of $H^{2-}$ with a lifetime of the order of $10^{-15}$ s.

Crossed beam methods have been employed by Tisone and Branscomb (1966, 1968), Dance *et al.* (1967) and Peart *et al.* (1970) to measure cross sections for $H^- + e \rightarrow H + 2e$. In these experiments the electron and ion beams crossed at right angles and, as the interaction energy (energy in centre of mass coordinates) was reduced below about 25 eV, it became progressively more difficult to obtain accurate results. A technique has now been developed in which the beams intersect at 20°. This has the advantages that the interaction energy of the particles can be much less than their energies in the laboratory frame and the spread of their interaction energies is reduced.

Figure 1 illustrates cross sections which were measured absolutely for interaction energies between 12 and 17·5 eV. The 90% confidence limits of random error and the estimated energy spread (full width at half height) are indicated for each point. The full symbols refer to measurements made with inclined beams and, for comparison, the results previously reported in this energy range by Peart *et al.* are shown by the open symbols. The excellent agreement between these two independent measurements and the enhanced resolution of the newer results can be seen. In addition, there is a pronounced structure in the detachment cross section which could be attributed to an excited state of $H^{2-}$ with a lifetime of order $10^{-15}$ s.

To verify that this structure was not of instrumental origin, the inclined beam experiment was performed with ion beam (laboratory) energies of 7, 8 and 10 keV, so that different electron energies were required to produce the same interaction energy. The points taken with these three ion energies are identified in the figure caption and it can be seen that the structure was consistently repeatable.

To determine the true laboratory energy of the electron beam, measurements were made of the function for single ionization of $Ne^+$ by electrons. This function is known to rise almost linearly from threshold (Dolder *et al.* 1963) so that the measured intercept on the energy scale could be compared with the ionization energy of $Ne^+$. This indicated that electrons produced by the present gun had $1{\cdot}0 \pm 0{\cdot}4$ eV

less energy than the potential difference applied to the gun. Appropriate corrections are included in the results presented in figure 1 and the energetic position of the resonance is expected to be accurate to within 0·2 eV.

Further experiments are in progress to extend the energy range of these measurements.

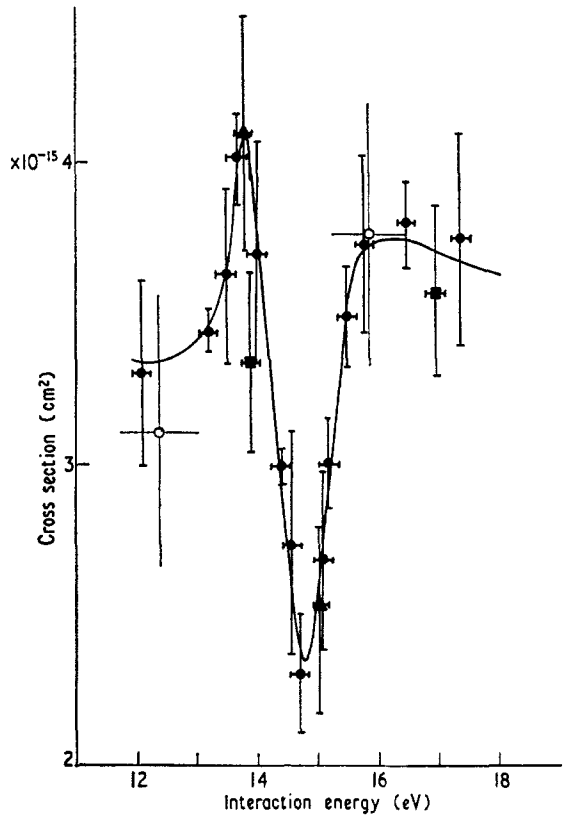


Figure 1. Cross sections for detachment from $H^-$ by electron impact. The symbols ■, ● and ▲ respectively refer to measurements with inclined beams in which the ion beam laboratory energies were 7, 8 and 10 keV. The open circles denote earlier measurements by Peart *et al.* Estimates of energy resolution and 90% confidence limits of random error are shown for each point.

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B. Peart
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*30th October* 1970

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# The quadrupole moment of $CO_2$, measured from the far infrared spectrum

**Abstract.** A correction for the quadrupole–quadrupole interaction energy is applied to the quadrupole moment of $CO_2$ measured from the far infrared collision-induced spectrum. The resultant values for the quadrupole moment of $CO_2$, obtained using two different theoretical equations, are $(4{\cdot}6 \pm 0{\cdot}3) \times 10^{-26}$ esu cm$^2$ and $(4{\cdot}3 \pm 0{\cdot}4) \times 10^{-26}$ esu cm$^2$ respectively ($(4{\cdot}6 \pm 0{\cdot}3) \times 10^{-31}$ C m$^2$ and $(4{\cdot}3 \pm 0{\cdot}4) \times 10^{-31}$ C m$^2$ in SI units).

We have recently presented measurements of the temperature variation of the far infrared absorption which occurs in compressed $CO_2$ gas (Harries 1970), and values of the quadrupole moment of $CO_2$, $Q_{CO_2}$, derived from those measurements. The quadrupole moments were derived using two well-known theoretical expressions, and were both based, as has been customary in previous works, on the Lennard-Jones form of the intermolecular pair potential, which describes the attractive dispersion forces by a $R^{-6}$ term and the repulsive forces by a $R^{-12}$ term (where $R$ is the separation of two molecules a and b). However, the quadrupole field in $CO_2$ is both strong and highly anisotropic, and Bose and Cole (1970) have shown that the introduction of a term describing the quadrupole–quadrupole energy is of significance. The present letter is intended to apply the corrections discussed by Bose and Cole (1970) to our own measurements.

The quadrupole–quadrupole interaction energy for two colliding molecules a and b is given by (Hirschfelder *et al.* 1954)

$$U_{QQ} = \frac{3}{16}\frac{Q_a Q_b}{R^5}\{1 - 5\cos^2\theta_a - 5\cos^2\theta_b - 15\cos^2\theta_a\cos^2\theta_b + 2(\sin\theta_a \sin\theta_b \cos(\phi_a - \phi_b) - 4\cos\theta_a\cos\theta_b)^2\} \quad (1)$$

where $\theta_a$ and $\theta_b$ are the angles subtended by molecules a and b to the line joining their centres, and $\phi_a$ and $\phi_b$ are the corresponding azimuthal angles to the line.

The inclusion of this term requires the Lennard-Jones pair potential function $U_{LJ}(R)$ to be replaced by

$$U_{LJ}(R) + U_{QQ}(R, \theta, \phi, Q_a, Q_b) \quad (2)$$

where the explicit functional dependence of $U_{QQ}$ is shown. Bose and Cole (1970) have given the results of applying this correction in graphical form.

Several other (small) correction terms are given by Bose and Cole and we have also applied these. They are: (i) the effect of anisotropy of the molecular polarizability; (ii) the reaction of the induced dipole moment in molecule b back onto molecule a, giving rise to a small interaction potential; (iii) the quadrupole-induced