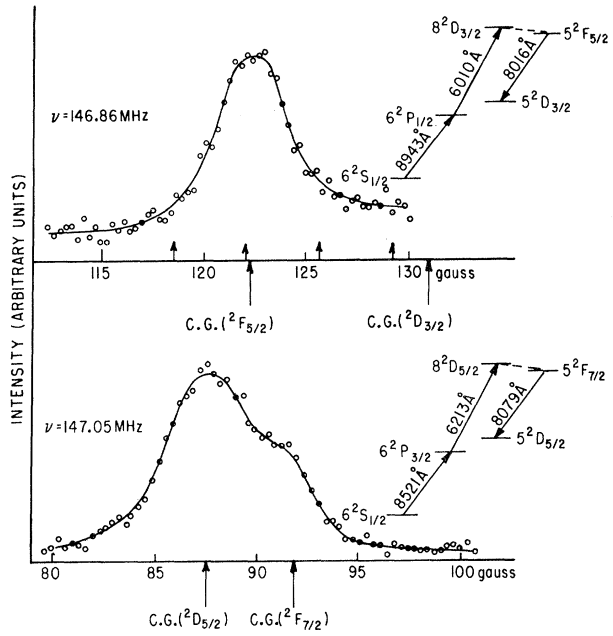

FIG. 3. Optical double resonance curves with signals from the $5^2F_{7/2}$ and $5^2F_{5/2}$ levels in Cs^{133}. The center of gravity (C.G.) for the F states and the position of the D resonance also occurring in these experiments are indicated. Sampling time for each of the curves is about 1 h.

constants are estimated:

$$|a(5^2F_{7/2}\ Cs^{133})| < 1.0 \text{ MHz}$$

and

$$|a(5^2F_{5/2}\ Cs^{133})| < 0.7 \text{ MHz}.$$

Measurements of the hyperfine structure of other highly excited alkali states and experiments for determining the signs of the coupling constants in the states studied in this work are in progress.

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Determination of the He^4-He^4 Repulsive Potential up to 0.14 eV by Inversion of High-Resolution Total–Cross-Section Measurements

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High-resolution measurements of the He^4-He^4 total scattering cross section are presented for reduced collision energies between 0.2 and 200 meV. Clear evidence for the Ramsauer-Townsend effect is observed and thirteen backward glory extrema are resolved. From these extrema we derive the energy dependence of the s phase shift. Applying the semiclassical inversion method proposed by Miller we then compute the repulsive potential up to 0.14 eV.

Knowledge of the interaction between two He^4 atoms in the ground state has been greatly increased in recent years. Relative differential scattering cross-section measurements at fixed energies[1-3] give sufficient information on the interaction potential only at energies which are not

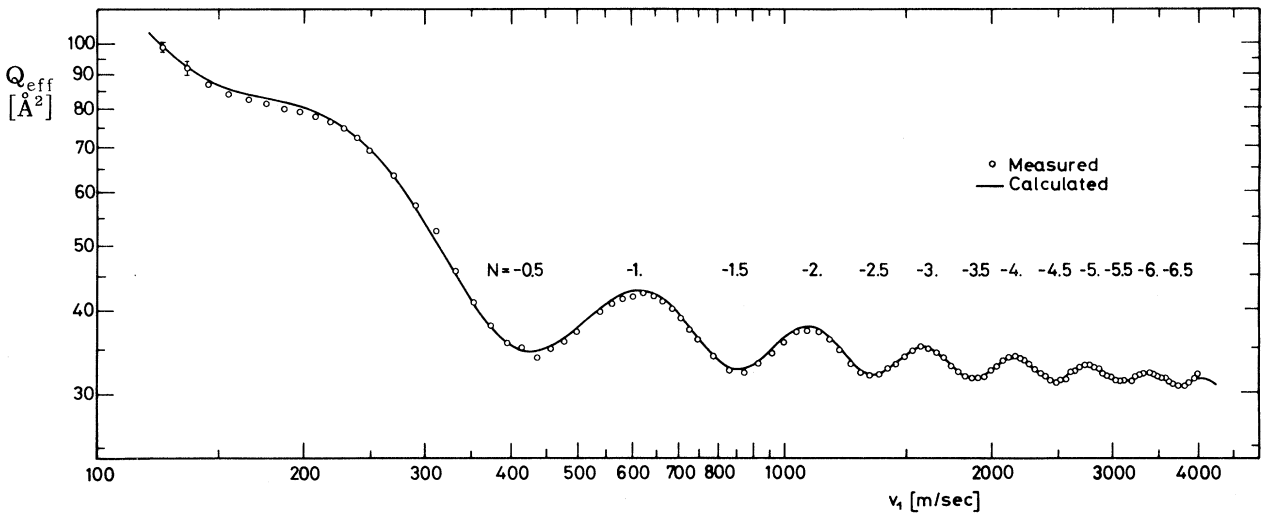

FIG. 1. Measured and calculated total effective scattering cross section Q_{eff} for He^4-He^4 as a function of the primary beam velocity v_1 (velocity resolution 6%). Scattering chamber temperature is 1.57°K. The theoretical curve is calculated from the potential explained in the text. N is the extrema index of Ref. 4.

too small.[3] However, total scattering cross-section measurements give this information in the entire energy range. At reduced energies $K > 2$ a powerful method for determining the repulsive region of the potential is to measure the backward glories[4,5] of the total cross section. Previous measurements of this type[6-8] can determine the repulsive potential in only a small interval because of the limited energy range. In the low-energy region (including $K < 2$) total scattering cross-section measurements are also used to derive the properties of the potential in the well.[8] At small energies ($K < 0.5$) the He^4-He^4 system satisfies the conditions of an atomic Ramsauer-Townsend effect[9-11,5]: The total cross section shows a deep minimum at one particular velocity associated with the passage of the s-phase shift through zero, while higher phase shifts are also small. An experimental resolution of this effect would give valuable information on the He^4-He^4 potential well.

We report here measurements of the He^4-He^4 total effective scattering cross section with high energy resolution in the energy regions discussed above ($0.2 < K < 200$). Except for several modifications, the apparatus used is that described previously.[12,13] The He^4 primary beam is velocity selected (effective resolution half-width 6%) and then scattered by He^4 in a scattering chamber maintained at 1.57°K by a pumped He^4 bath. Additional details will be given in a forthcoming paper.

The experimental results are shown in Fig. 1. Using a symmetric selector[14] the velocities v_1 are determined to within 0.3%. The experimental Q_{eff} values are obtained as relative cross section measurements. The standard deviation of each measurement is generally smaller than 1% unless otherwise indicated in Fig. 1. An absolute cross section scale is established by comparison with theoretical calculations below.

As can be seen, all thirteen backward glory extrema in the measured energy range are clearly resolved. The oscillations are labeled with the extrema index N of Ref. 4. At low energies the Ramsauer-Townsend effect is visible as a plateau. The minimum of the cross section in this region cannot be resolved with the present experimental technique. It may be possible to obtain such a resolution with a scattering chamber cooled by a He^3 cryostat or with a secondary beam crossing the primary beam at the proper angle.[15] We intend to use the second method in future measurements.

The measured backward glory extrema in Fig. 1 lead directly to the repulsive potential using the semiclassical inversion method proposed by Miller.[16,17] In this method the semiclassical integral representation of the s phase shift is transformed to yield the classical turning point $r_0(E)$:

$$r_0(E) = (2k)^{-1} - (2/\pi)(\hbar^2/2\mu)^{1/2}\{\pi \int_{-1/2}^{\eta(E=0)} d\tilde{n}[E - E(\tilde{n})]^{-1/2} + \int_{\eta_0(0)}^{\eta_0(E)} d\tilde{\eta}_0[E - E(\tilde{\eta}_0)]^{-1/2}\}, \quad (1)$$

where E is the relative collision energy, k is the relative wave number, μ the reduced mass, $E(n)$ is the inverse function of the WKB bound-state eigenvalue function $n(E)$, and $E(\eta_0)$ is the inverse function of the energy dependence of the s phase shift $\eta_0(E)$. From $r_0(E)$ we obtain the potential V at r_0 via the turning-point condition

$$V(r_0) = E - \hbar^2(8\mu r_0^2)^{-1}. \quad (2)$$

To obtain r_0 we must evaluate the three terms in Eq. (1). The first term is straightforward; it is due to the centrifugal part of the effective potential and occurs also for angular momentum $l = 0$ since in our case the effective potential must be written in the $l+\frac{1}{2}$ version (see footnote 5 in Ref. 17). The second term requires an assumed potential well. For the third term, which in our case gives the dominant contribution, the s phase shift $\eta_0(E)$ must be known in the semiclassical approximation, since the Miller formula is only valid here. For energies $E \geq E_g$ (E_g backward glory minimum energy) $\eta_0(E)$ can be calculated semiclassically at the backward glory extrema positions E:

$$\eta_0(E) = [N(E) - \tfrac{1}{4}]\pi - \tfrac{1}{2}\varphi(E), \quad (3)$$

N being the extrema index.[4] In our case the function $\varphi(E)$ is a small correction term which depends so weakly on the shape of the repulsive potential that the knowledge of the final inverted potential is not necessary for evaluating Eq. (3). At $E < E_g$, $\eta_0(E)$ must be computed semiclassically for an assumed potential.

Therefore, in order to compute a repulsive potential for values $V \geq V_g$ [V_g corresponding to $E = E_g$ in Eq. (2)] by inversion of a measured $\eta_0(E)$ curve for $E \geq E_g$, we need in addition an assumed potential for the region $V < V_g$; we call this the starting part. The inverted repulsive part together with the starting part then represents the new derived potential.

In a preliminary analysis we use the "best-fit" potential proposed by Cantini *et al.*[7] for the starting part because it fits the data well in Fig. 1 up to $E \sim 30$ meV.[18] The repulsive part up to 0.14 eV is then inverted using the measured $N(E)$ spectrum.

Figure 2 shows the phase shifts $\eta_0(E)$ used in Eq. (1). The resulting repulsive potential $V(r)$ is presented in Fig. 3. As expected the repulsive part is "softer" than the Lennard-Jones (11, 6) shape of Ref. 7 for $V > 30$ meV. The potential values agree well with those reported previously.[3,8,19-21]

To check the reliability of the applied inversion procedure we have computed the total effective scattering cross section using the derived potentail. Agreement is generally good as can be seen in Fig. 1. However, small deviations do occur.[22] We believe that the starting part is more responsible for these deviations than the inverted part for the following reason. Although the inverted values are influenced by the chosen starting part [for the values in Fig. 3 the second term in Eq. (1) contributes 26% to the $r_0(E)$ value at $E = 17$ meV and 13% at $E = 142$ meV], identical results are obtained with two further starting parts (ESMSV-II[3] and mLJ-D[8]), i.e., the inverted results remain unaffected for starting parts which

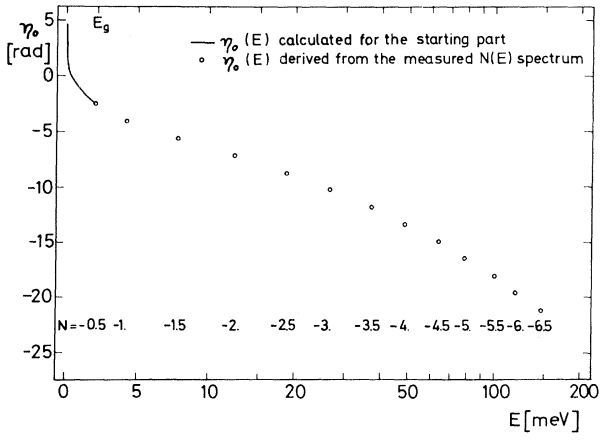

FIG. 2. The s phase shift function $\eta_0(E)$ used for the inversion.

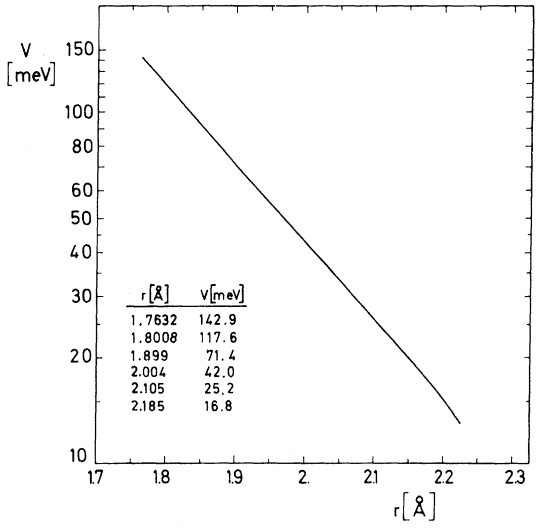

FIG. 3. The upper repulsive part of the He^4-He^4 potential determined by inversion. Exponential fit: $V = 0.329 \exp[15.01(1 - r/2.96\ \text{Å})]$ meV.

are not too different. Thus we believe that the inverted part is quite well established.

Accordingly the main error for $r(V)$ in Fig. 3 is due to the error in the $N(E)$ points where $\Delta E/E \sim 2\%$. This gives $\Delta r/r \sim 1\%$ from Eq. (1).

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Electron Loss in High-Energy Oxygen-Ion Collisions*

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The 90° electron spectra from oxygen-ion single collisions with Ar have been measured at energies of 17 to 41 MeV and charge states of 3+ to 8+. A broad peak in the spectra is observed and identified as electrons lost from the incident ion. A simple model of the electron-loss process is described which supports the identification.

Fast heavy-ion–atom collisions result in the production of copious amounts of electrons. The energy spectra of the emitted electrons have been studied in detail for incident heavy-ion energies below 500 keV. Recent reviews of these measurements have been given by Ogurtsov[1] and by Rudd and Macek.[2] At observation angles of 90° or greater, the continuous electron spectra are found to be monotonic functions of the electron energy, decreasing nearly exponentially with increasing electron energy. Superimposed on the continuous backgrounds, monoenergetic electrons have also been observed from autoionization and Auger de-excitation of the target and projectile.

The subject of this Letter is the continuous spectra in similar measurements at much higher energies—in particular, a prominent peak in these spectra which is unique to collisions at these energies. This peak is shown, on the basis of the incident energy and charge-state dependence, to be attributable to electrons knocked out of the incident ion. A simple model of the electron-loss process based on elastic electron scattering is described which semiquantitatively supports this identification.

We have measured the 90° electron spectra in single collisions of oxygen ions with several gases at energies of 17.5 to 40.8 MeV using charge states of 3+ to 8+. The oxygen beams were produced in the University of Washington's FN tan-