ing scattering angle. The ground-state curve, however, falls more rapidly than the excited-state curves. Consequently, if the photon spectrum were taken at a larger scattering angle, the 19-MeV peak should be even more prominent. From Fig. 2, we see again that the two 4^- states provide about half of the total (p,γ) strength in this excitation-energy region.

The direct-radiative-capture picture which we have presented gives a good fit to the observed $^{11}B(p,\gamma)$ spectrum, for excitation energies up to 25 MeV. This suggests that the primary reaction mechanism is dominated by formation of particle-hole states, as was conjectured by Arnold.[10] It also shows that a model which successfully reproduces the ground-state photonuclear transitions with photon energies 40–140 MeV is also able to account for the radiative-capture transitions if the exchange-current contributions in both processes are properly taken into account.

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Composition of He Metastable Beams Formed by Charge Exchange in He^+–Alkali-Metal Collisions at Medium Energy

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The composition of He metastable beams formed by charge exchange on alkali-metal vapors is determined by a time-of-flight analysis. The relative abundance of the two components $He(2^3S)$ and $He(2^1S)$ is measured in the 100–1500-eV energy range. It is shown that a pure $He(2^3S)$ beam is obtained with sodium as the exchange target, whereas rubidium is found to be the most efficient target to yield a $He(2^1S)$ beam. Comparison is made with theoretical predictions.

Collisions involving excited atoms, especially metastable atoms, have received much attention in the past few years. It is well known[1-3] that intense metastable beams of hydrogen and rare gases can be produced by charge-exchange collisions of the corresponding ions with alkali-metal atom targets. Since the ionization potentials of the alkali-metal atoms are close to those of the rare-gas atoms in their first excited states, these charge-exchange reactions are nearly resonant and yield large cross sections. In the case of helium, the two metastable states $He(2^1S)$ and $He(2^3S)$ can be produced *a priori*. However, only the sum of the singlet and the triplet total charge-exchange cross section has been measured.[2,4] Although the ground-state and metastable fractions of the beam are known from the measurements of Neynaber and Magnuson[5] and McCullough, Goffe, and Gilbody,[3] the relative population of the $He(2^1S)$ and $He(2^3S)$ states has never been determined to our knowledge. The standard reference to date for the He metastable production is the theoretical prediction of Olson and Smith.[6] The only experimental determination of a beam composition concerns the formation of a neon metastable beam using a laser-induced fluorescence (LIF) technique.[7] In this paper we report the first *direct* measurement of the relative $He(2^3S)$ to $He(2^1S)$ population of a metastable helium beam obtained by charge exchange with Na, K, Rb, and Cs at-

oms in the 100–1500-eV energy range.

Identification of the various charge-exchange channels is obtained by a time-of-flight (TOF) measurement of the characteristic energy losses undergone by the scattered neutrals. The incident He^+ beam, produced in a discharge ion source, suffers charge exchange in an alkali oven. A portion of the neutralized beam, which is scattered through an angle, is detected with a channel-plate detector. A detailed description of the TOF spectrometer is given elsewhere.[8] The whole experiment is monitored by a PDP-11 computer. The small energy spacing (0.8, 0.35, and 0.25 eV) between the four $n=2$ He sublevels (2^3S, 2^1S, 2^3P, and 2^1P) requires a high energy resolution of the apparatus. This resolution was achieved by a reduction of the discharge current in the ion source (~ 10 mA) to narrow the energy spread of the ion beam and the use of long flight distances (4.5 m for $E \leq 500$ eV and 7.5 m for higher energies) to increase the timing resolution. The overall energy resolution ΔE is about 250 meV. The low beam intensities lead to a limitation in the accessible angular range of $\theta \leq 2°$ at 100 eV and of $\theta \leq 0.5°$ at 1000 eV. The angular resolution is $\Delta\theta = 0.2°$ for $E \leq 500$ eV and $\Delta\theta = 0.1°$ for higher energies. All the data were obtained in single-collision conditions. The determination of the origin of the energy-loss scale ($\Delta E = 0$) has been one of our major problems. It was overcome by using as energy origin the peak produced in the energy-loss spectra by resonant charge exchange at $\theta \simeq 0°$ from He^+-He collisions, since in this case the energy loss is completely negligible. In order to get rid of the contact potentials in presence of an alkali-metal vapor in the target cell, this peak is obtained by subtracting the spectrum recorded with only the alkali-metal vapor in the cell from the spectrum corresponding to a mixture of helium and alkali metal; see Fig. 1. This careful determination of the energy-loss origin showed that a wrong assignment has been given previously for the He^+-Cs case in a preliminary report.[9]

Typical spectra given in Fig. 2 show that mainly the 2^3S, 2^1S, and 2^3P states are produced at $\theta = 0°$. This result is also found for $E\theta \leq 150$ eV deg. At larger angles, charge exchange into He(2^1P),

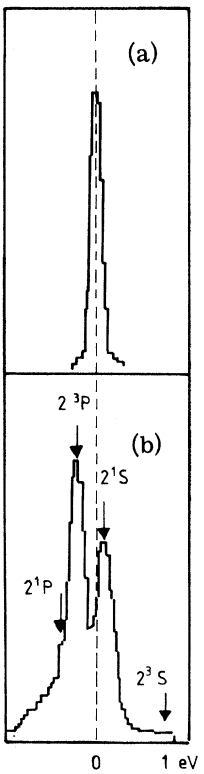

FIG. 1. (a) He^+/He spectrum giving the energy-loss scale origin (see discussion in text); (b) He^+/Cs spectrum at $\theta = 0°$ and $E = 200$ eV.

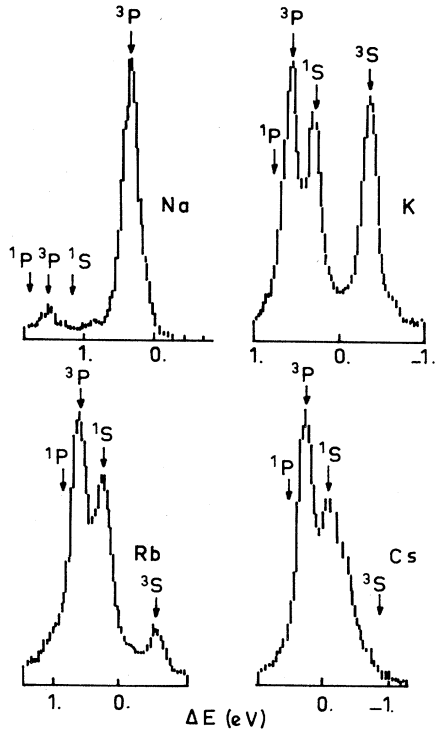

FIG. 2. Typical TOF charge-exchange energy-loss spectra for He^+ collisions on Na, K, Rb, and Cs at 750 eV and $\theta = 0°$.

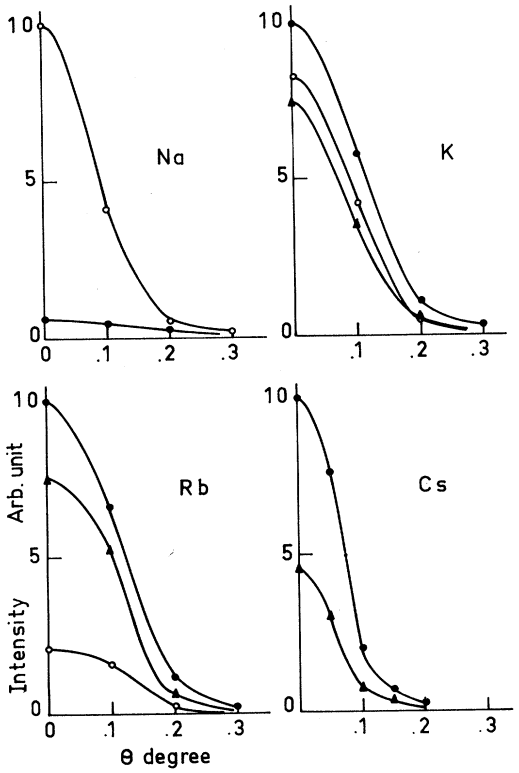

FIG. 3. Angular beam profile at $E = 750$ eV for each alkali-metal target. Open circles, He(2^3S); triangles, He(2^1S); and filled circles, He(2^3P).

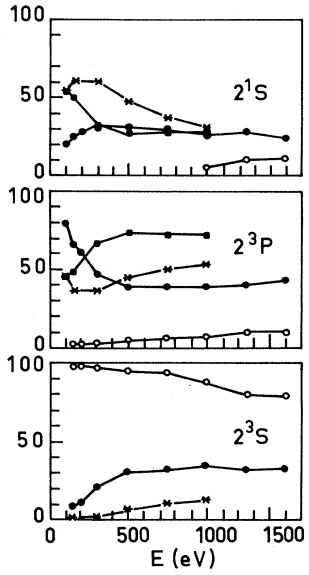

FIG. 4. Fractions of He excited states present in the neutral emerging beam as a function of energy for each alkali-metal target (open circles, Na; filled circles, K; asterisks, Rb; and squares, Cs).

He($n \geq 3$) + M^+, and He($1s^2$) + M^{+}* channels,[10,11] where M stands for alkali metal, begins to appear. Figure 3 shows the "beam profile" for each He^+ state. As expected for a nearly resonant charge-exchange process, the intensity drops drastically with angle. Furthermore, in a restricted angular range the relative populations are almost independent of scattering angle. Thus we can deduce the beam composition from the data at $\theta = 0°$; see Fig. 3. Since the 2^3P state decays to the 2^3S state the final 2^3S population is given by the sum of the measured 2^3S and 2^3P components; see Table I and Fig. 4. The determination of the He 2^1P-state population requires a deconvolution of the experimental data. The amount of the He 2^1P state obtained by this procedure is too small to convey an accurate determination and only an upper limit of 10% can be claimed with reasonable confidence. This result is actually consistent with the 15% estimate of Neynaber and Magnuson.[5]

The results can be summarized as follows: (i) The He 2^1P state is not excited substantially. (ii) Only the Na target leads to the formation of a pure triplet metastable beam. (iii) On the other hand, none of the alkali metals allows the formation of a pure singlet metastable beam. However, a beam with more than 50% of the He atoms in the 2^1S state is obtained with rubidium for $E < 500$ eV and with cesium for $E \leq 150$ eV. Comparison of these results with the theoretical results of Olson and Smith[6] yields the following conclusions: (i) The very small quantity of the 2^1P state in a helium beam is in contradiction with the theoretical prediction. (ii) The authors do not predict

TABLE I. He(2^3S) total fraction [sum of He(2^3S) and He(2^3P) contributions] in the metastable emerging beam.

E (eV)	Na	K	Rb	Cs
100	...	80	46	46
150	100	75	39	49
200	100	73	...	59
300	100	67	40	67
500	100	69	53	73
750	100	70	61	72
1000	95	74	68	72
1250	90	73	...	...
1500	90	76	...	...

any 2^1S-state population in the case of cesium, in obvious disagreement with our result.

We conclude that, in addition to the practical interest of knowing the composition of metastable He beams, the present results should challenge theorists to improve the description of the collision mechanisms involved in these processes.

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Finite-β_e Universal-Mode Turbulence and Alcator Scaling

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A self-consistent theory of finite-β_e universal-mode turbulence is developed. Saturation results from resonance broadening of the electron response due to magnetic shear. Electron diffusion, for $\beta_e > m_e/m_i$, is due to the magnetic part of the fluctuations. The diffusion coefficient, $D = 0.1\,[T_e/(T_i+T_e)]^4\,(m_e/m_i\beta_e)(L_s/L_n)^2\,v_i\rho_i^2/L_n$, scales inversely with density, is independent of magnetic field, and is in excellent quantitative agreement with observations on the Alcator tokamak.

One of the principal theoretical goals in tokamak research is the development of a self-consistent turbulence theory for the short-wavelength fluctuations through to be responsible for anomalous transport. This paper presents a nonlinear turbulence theory for the finite-β_e universal instability. An approximate analytic solution of the coupled, nonlinear, eigenmode equations is obtained. The accuracy of this solution has been verified by numerical computations. The resulting formula for the anomalous electron thermal conductivity, Eq. (9), has many similarities with experimental observations, including absolute magnitude, and scaling with density, temperature, and ion mass. For typical tokamak regimes where $\beta_e > m_e/m_i$, the calculation constitutes an example of a self-consistent theory of stochastic[1] magnetic fluctuations.

Until recently,[2] most turbulence theories ignored shear in the equilibrium magnetic field. Without shear, turbulence mainly affects the ions. The basic saturation picture, as developed by Dupree,[3] balanced linear electron growth, $\gamma_e^{\,L}$, against nonlinear (turbulent) ion damping, $\gamma_i^{\,NL}$. Taking $\gamma_i^{\,NL} = k_\perp^2 D$ is the basis for the $\gamma_e^{\,L}/k_\perp^2$ estimates of the anomalous diffusion coefficient. However, recent theory[4] has found that $\gamma_i^{\,NL} \ll k_\perp^2 D$, because the ion-wave interaction is