Electron capture from a metal surface by slow, multicharged aluminum and carbon ions

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A time-of-flight technique has been used to measure residual charge in the scattering of laser-produced pulses of \( C^ {+} (k = 1 \text{ to } 4) \) and \( Al^ {m+} (m = 2 \text{ to } 5) \) ions from a well-outgassed amorphous gold-iridium surface under UHV conditions (2\( \times 10^{-7} \) Torr). Ions incident at 7° to the surface were specularly reflected. The analysis showed the survival of singly charged ions in the case of scattering 300-, 400-, and 500-eV/charge \( Al \) ions with neutrals representing the majority species. This is equivalent to a kinetic energy in a direction transverse to the surface of 4.5, 5.9, and 7.4 eV/charge, respectively, which ensures only minimal surface penetration. In the case of 280-eV/charge \( Al \) ions, only neutrals were detected. No residual ions were detected in either \( Al \) or \( C \) ions scattered through an angle of deviation equal to or greater than 45° within experimental error. In a separate experiment no residual ions were detected in the case of 400-eV/charge \( Al \) ions incident at 22.5° to a gold surface and specularly reflected. The results are explained in terms of Auger neutralization of the multicharged ions on the incoming pass and resonance ionization and neutralization of low-charge-state ions that emerge from the surface and change their charge on the outgoing pass. Under near adiabatic conditions, no residual charge is expected for either the aluminum or carbon projectiles. The presence of \( Al^ {+} \) under grazing-incidence and specular reflection is analyzed and discussed in terms of the nonadiabatic behavior of \( Al^ {+} \) ions emerging from the surface.

INTRODUCTION

In a previous publication\(^1\) we reported the survival of only singly charged aluminum ions when slow (near 400 eV per charge) multicharged aluminum ions (\( Al^{m+} \) where \( m = 2 \) to 6), incident at 7° to a gold surface, were specularly reflected. It was suggested that the ion-neutral fractions did not appear to be a strong function of the incident charge state and was consistent with a model in which the highly charged incident ions are rapidly Auger neutralized in a step-wise fashion\(^2\) to \( Al^ {+} \) with neutralization completed by resonance neutralization since the ground state of \( Al^ {0} \) is 6.0 eV, which is below the Fermi level of gold. Since that preliminary report the apparatus has been improved and we now can report more quantitative results.

APPARATUS

Figure 1 shows our apparatus. The ion source is a laser ion source.\(^3\) The laser has been upgraded in power since the works described in Ref. 3 were done. This upgraded source was used in Ref. 1 and was used in the study of the end-point energies of Auger-ejected electrons when multicharged ions are near a gold surface.\(^4\) The ions are produced by 15-ns 800-mJ bursts of neodymium-doped yttrium aluminum garnet (Nd:YAG) laser light focused onto a solid target. The resulting plasma plume advances toward the entrance of a 180° electrostatic analyzer where ion packets with a particular energy per charge are selected. The ion packets travel through a deceleration-acceleration einzel lens (\( L_1 \)), ion gate (IG), and acceleration-deceleration einzell lens (\( L_2 \)) to the collision chamber where the gold-iridium ion target is housed. Scattering from the target takes place near grazing incidence at about 7° to the surface. The ion packets then are specularly reflected down the long charge analysis arm. The scattered packets pass through a screened retarding gap (RG) where the charged component is slowed and allowed to drift in an equipotential environment provided by a positively charged drift tube (DT). The ions pass through an exit screen and are accelerated back to ground potential. The ions impact onto a Galileo Chevrom (channel plate) detector (\( C_1 \)) which we will refer to as a CEMA to be consistent with Ref. 4. The charge separation is thus done through a time-of-flight technique (TOF) where the neutral component of the scattered packet arrives in time before the ionic component.

The ion drift region is surrounded by a strong longitudinal magnetic field provided by magnetic coils (MC's). The magnetic field is necessary to prevent ion loss due to space-charge repulsion effects. The CEMA detection efficiency is not affected by the magnetic field because the pore size of the channel plate is much smaller than the Larmor radius of the secondary electrons induced in CEMA.

The CEMA detector is operated in this study with the front end at ground potential. This insures that for each ion packet that is scattered from the gold-iridium target the neutral component and the surviving \( Al^ {+} \) component will each strike the CEMA at the same velocity. Since the first ionization potential for aluminum is only 6.0 eV, appreciable secondary electron production in the CEMA by potential ejection is not expected, and thus secondary electron production in the CEMA is essentially all due to kinetic ejection. Operating the CEMA front end at ground potential allows us to detect the neutral com-
End-point energies of electrons ejected during Auger neutralization of slow, multicharged ions near metal surfaces

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A study has been done of the end-point energies of electrons ejected during Auger neutralization of slow, multicharged ions near metal surfaces. The study includes a wide variety of ions. Experimental results are presented for Al$^{2+}$ and C$^+$ ions incident on a gold surface, where $z = 2-5$ and $n = 2-5$. Ions from a laser-ion source are processed to produce ion pulses with incident energies ranging from 40 to 280 eV/charge. Data published by Hagstrum for 200-eV He$^{2+}$, Ne$^+$, Ar$^+$, Kr$^+$, and Xe$^+$, on tungsten, where $n = 2$ and 3, are analyzed along with the work of Varga, Hofer, and Winter for low-energy Ne$^{2+}$, Ar$^{2+}$, Ar$^{3+}$, Kr$^{2+}$, and Xe$^{2+}$ on tungsten. It is concluded that the high-energy end of the Auger emission is dominated by single-electron capture by the ion and an internal conversion process involving direct coupling of optically allowed transitions in the lower-lying excited states of the singly neutralized ion to the top of the conduction band of the metal target. It is shown that a considerable fraction of the neonlike Al$^{3+}$ ions from the laser-ion source are in a metastable state and are neutralized through autoionization.

INTRODUCTION

The first definitive study of Auger neutralization of slow ions near metal surfaces was published by Hagstrum$^{1,2}$ in 1954. In the first of these classic papers, he presented experimentally determined electron yields and energy distributions of electrons ejected during the neutralization of slow rare-gas ions near an atomically clean tungsten surface. In the second paper$^2$ he gave a theoretical analysis of his experimental results for singly charged ions. However, Hagstrum's published data also included the results for electrons ejected in the neutralization of the multicharged ions He$^{2+}$, Ne$^+$, Ar$^+$, Kr$^+$, and Xe$^+$ where $m = 2-3$, $n = 2-4$, and $p = 2-5$. From an analysis of the electron yields Hagstrum concluded that neutralization of multiply charged ions near a surface is likely to occur in a series of stages where each stage excites an electron inside the metal. No analysis of the end-point energies was performed. More recently, Varga et al.$^3$ have obtained higher-resolution spectra of Auger electron energies produced by $\leq 30$-eV Ne$^{2+}$, Ar$^{2+}$, Ar$^{3+}$, Kr$^{2+}$, and Xe$^{2+}$ impact on tungsten.

Arifov et al.$^4$ have treated Auger neutralization of multiply charged ions near a metal surface, pointing out the ion can undergo a series of resonant and Auger neutralizations to high-lying excited states as the ion approaches the metal. Figure 1 schematically shows Auger neutralization where an electron is captured from the conduction band into an excited state of the singly neutralized ion. Any loss in excitation energy during the neutralization process goes into exciting another electron in the conduction band. If the excitation energy transfer to the conduction-band electron is sufficient and its momentum is properly directed toward the surface, then it may escape the potential well at the surface and be detected as an Auger-emitted electron. The ejected electron may have lost energy in collisions with the conduction electrons before finding itself free of the surface. Thus the end-point energy electron in the broad energy spectrum of the emitted electrons provides a unique probe of the neutralization processes. These end-point energy electrons are the ones that have been given initially the maximum energy transfer in the neutralization process, have suffered little collisional loss with other conduction electrons, and have their origin in the top of the conduction band where the potential well depth is the work function $\phi$. These electrons thus have reason-
to propagate normal to the growth striations. There is no similarly strong tendency to force propagation of dislocations in undoped material.

The existence of prominent helicoidal dislocations in highly doped LEC GaAs is evidence of point defect supersaturation in the absence of large mechanical stresses. It appears that by strengthening the crystalline lattice and hence reducing the total number of dislocations so that a critical supersaturation of native point defects exists, Si and In doping indirectly drive the formation of helicoidal dislocations. Once the helicoidal dislocations have compressed during climb, they become excellent centers for impurity precipitation. Dislocation loops presumably punched out from these precipitates are seen in Figs. 4 and 5. This reasoning helps explain the identical defect morphology seen in Si-doped and In-doped material despite the differences in concentration, solubility, and site occupancy of the dopants. Furthermore, the large dislocation density and lower activation energy for climb in undoped LEC GaAs permit similar point defect interactions and impurity segregation throughout the material without helicoidal dislocation formation. It has been suggested that thermal stresses play a role in creating defects in the center of the ingot. The work reported here shows that the morphology cannot be explained by such arguments alone. This in turn implies that control of the thermal gradient is necessary but may not be sufficient to obtain defect-free LEC GaAs.

Straight and helicoidal defects propagating normal to growth striations were also observed during the development of gadolinium gallium garnet growth procedures. These defects were found to be caused by nonstoichiometry of the melt. It is not possible, on the basis of the results reported here, to determine the type of point defects responsible for the morphology found in highly doped LEC GaAs. Stoichiometry fluctuations during growth could be a cause. The work reported here thus suggests it is important to both measure and control the stoichiometry of the melt in order to eliminate the central defects from highly doped LEC GaAs wafers.

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References


Observation of fractional neutralization of slow multicharged ions by impact on a metal surface

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We report the first observation of energy losses and fractional neutralization of slow multicharged ions incident on a metal surface. Data were obtained on 374 eV per charge aluminum 3<z<6 ions incident on an uncharacterized gold surface at a grazing angle of 7° and scattered through 14°. The resulting atoms consisted of about 60% neutral and 40% singly charged ions in the case of incident z = 4 ions. The scattering process did not appreciably broaden the ion linewidths. The apparatus makes use of a laser generated heavy ion source.

The scattering of slow, multicharged ions (z>3) by metal surfaces has never been experimentally studied except through measurement of total secondary electron yields. Neutralization of such a projectile at a metal surface can be accompanied by prolific Auger electron ejection since the total neutralization energy can be very large. However, it is difficult to understand the process in detail using this technique since the details are integrated in the total electron yield.

We are attempting to understand the details in a different set of experiments. We report here the preliminary results of one facet of these experiments. In fact, we report the first measurement of neutralization fractions of slow multicharged ions scattered from a surface. We also include pre-
Time-resolved optical emissions from high-current relativistic electron beams propagating in 150-mTorr air

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Results of a time-resolved study of optical emissions from high-current relativistic (6.5 MeV) electron beams propagating in air at a pressure of 150 mTorr are presented. The emissions included N$^+$ lines at $\lambda\lambda$ 4803, 4630, 4552, and 4530 Å. Data were obtained on a single-shot basis by simultaneously recording the temporal history of all four ion lines. For propagating electron beam pulses, each ion line exhibited peak intensity a few microseconds after the passage of the 80-ns-wide electron pulse. This behavior is explained on the basis of inductive (magnetic) energy storage in the return current plasma channel. Spatially integrated plasma temperatures are measured to be in the 20 000–30 000 K range, reaching a maximum when the inductive energy storage has gone to zero.

I. INTRODUCTION

Very little research has been reported regarding optical emissions induced by an intense (tens of kiloamps) pulse of relativistic electrons propagating in gases. Examples in the open literature are rare.1,2 As a consequence, a spectroscopic study of optical emissions induced by such a beam in air was undertaken at the Air Force Weapons Laboratory, Kirtland Air Force Base in Albuquerque, New Mexico using the Pulse-Rad 1590 electron beam generator. Results of a photographic spectral survey have been published elsewhere.1 The low-pressure air research reported here is part of a time-resolved follow-up.

A qualitative time-resolved study using streak photography has been reported for a beam in 350-mTorr air in which late-time atomic emissions were noted microseconds after the passage of the pulse.3 That work would be classified as a low-pressure study, as this present work, where nitrogen- and oxygen-ion emissions dominate the spectra.1 At higher pressures (> 1 Torr), the molecular nitrogen spectra dominates.1

The plasma temperatures can be measured spectroscopically. Temperatures in lightning strokes have been measured by Pruitt4 by using time-integrated (photographic) nitrogen-ion line intensity ratios. This technique has been also used by Wright5 and Hughes1 to determine time-integrated temperatures in plasma channels generated by intense relativistic electron beams. The intent of the present study was to measure the time-resolved intensity ratios of N$^+$ lines to determine the plasma temperature as a function of time.

II. BEAM AND PLASMA CONSIDERATIONS

Many details of beam propagation such as the basic atomic processes in gas chemistry and plasma instabilities are not well known; however, the subject of beam propagation can be described in terms of basic beam electromagnetic interactions with plasmas.6 An intense electron beam propagating in a gas creates a plasma channel which is sensitive to the self-fields of the beam pulse. The large azimuthal magnetic fields associated with the high-current beam pulse produce beam pinching. The rapidly changing fields near the beam head create strong electric fields which drive the newly created plasma electrons in the opposite direction (Lenz’s law). This return current of back electrons reduces the net current in the plasma channel. Electric fields are also created in the beam tail caused by the collapsing beam magnetic field which are in the direction to drive the plasma electrons in the beam direction. The magnetic fields associated with all currents compress the diamagnetic plasma. The return current persists in the channel after the beam pulse passage and decays with an inductive time constant $L/R$, where $R$ is the inductance and $R$ is the resistance in the plasma channel.

Thus, the following picture is presented. At the head of the e-beam pulse, electron avalanche processes occur. Fast secondary electrons, delta rays, etc. create a plasma channel in the wake of the beam head. The rise and fall of the e-beam current pulse produces large electric fields which drive the plasma electrons. Ionization rates are high. Immediately after the passage of the e-beam pulse, highly energetic nonthermal electrons are entrained in the plasma channel by the constricting self-magnetic field. Energy is stored in this field or, from an atomistic point of view, in the kinetic energy of these entrained electrons.

The return current that persists in the plasma channel after the e-beam pulse has passed will continue to ohmically heat the plasma channel. The energy stored in the magnetic field surrounding the channel $LI^2/2$, where $L$ is the coaxial inductance and $I$ is the net current, will be dissipated in plasma heating. The ohmic heating loss in the channel is simply $I^2R$, where $R$ is the resistance in the channel.

III. SPECTROSCOPIC TEMPERATURE MEASUREMENTS

The late-time temperature that one measures spectroscopically in the return-current plasma channel is that which describes a Maxwellian distribution of plasma electrons dominated by the reaction rates among the excited states of the optical emitters. It is first necessary to show that conditions for local thermodynamic equilibrium (LTE) exist in the excited states. Estimates of the validity of LTE require
Heavy-ion source using a laser-generated plasma transported through an axial magnetic field

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Results of transporting a laser-generated plasma through magnetic fields are reported. Plasma plumes have been generated in strong magnetic fields, in directions both transverse and parallel to the field. Collective effects are demonstrated by the plasma while in the high-density state near the laser target. The formation of the plasma and its transport through an axial magnetic field enhances the relative amount of highest charge states and the lowest charge states. The focusing properties of the magnetic field near the extractor gap can prove useful in enhancing ion density at the anode aperture of the extractor gap. It is suggested that the duty cycle of laser ion sources can be extended by simply increasing the ion flight time through the magnetic field from the laser target to the extractor gap without appreciable loss of ions. Further, it is suggested that energy spread in a given ion species can be made small by using an extractor potential programmed to increase in time relative to the laser fire time.

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I. INTRODUCTION

Experimental results were reported in a previous publication for extraction of heavy ions from a freely expanding plasma generated by 20-MW bursts of 1.06-μm radiation from an active Q-switched Nd:YAG laser at a target power density near 10^11 W/cm^2. Ions were extracted from the plasma by applying a 15-kV potential across the extractor gap. Potentially useful properties of the laser-generated plasma plume as a source of ions were pointed out. It seems appropriate to again enumerate these properties: (1) a copious supply of ions per laser pulse, (2) high states of ionization, (3) short plasma generation times, (4) highly directional plasma plumes which can be efficiently directed along a beam axis, (5) versatility in producing not only a multiplicity of charge states but also a variety of nuclear species, (6) a freeze in charge states with little recombination effects after the initial plasma generation, (7) simplicity in plasma generation since the target at high potential is optically connected to the laser at ground potential, and (8) the source contributes essentially no gas load to the vacuum system.

However, the most obvious drawback to the laser source is its duty cycle since the repetition rate of a high-power laser is not particularly high. Our laser, a Holobeam 5050Q, has a maximum repetition rate of 50pps. The length of a typical magnetically separated ion pulse under the conditions of Ref. 1 (30-cm drift distance from the target to the extractor) was ~10 μsec. This would produce a maximum duty cycle of only 0.05% with our laser. Somewhat higher repetition rates are now available in present day lasers, but it is clear that an important concept in making the laser ion source more useful is increasing the duty cycle by other means.

One possibility of increasing the duty cycle is the use of magnetic confinement of the ions. However, past attempts in this direction have not been encouraging. Haught et al. demonstrated some containment of a LiH plasma in a simple magnetic bottle where the plasma generated by a laser focused on a pellet target, situated near the center of the bottle, was allowed to expand in the presence of a magnetic field. The experimental evidence bore out the theoretical prediction that the plasma expansion transverse to the field could be slowed and even stopped, the lost kinetic energy going into heating the plasma, resulting in a redirected expansion along the magnetic axis. The ions then escape through the bottle necks first, Li^+ followed by the other ions with H^+ the last to leave. Escape times varied from a few microseconds to about 150 μsec for the H^+ component. Suvorov et al. performed a similar experiment with aluminum pellets. However, they concluded that there was no evidence of any appreciable slowing of the motion transverse to the field.

Their explanation was that the transverse motion separates the charge producing an electric field across the plasma which in turn leads to an EXB drift across the field lines. They further concluded that at most 5% of the plasma was trapped for a very few tens of microseconds. This motion transverse to the field is in qualitative agreement with the experimental results reported by Bruneteau et al.

II. APPARATUS

Several modifications were made on the basic apparatus described in Ref. 1. The magnetic separation of charge states used the same basic technique. The ions are accelerated across an extraction gap giving the ions a known velocity large compared with the initial plasma velocity. The anode aperture diameter was increased from 1/4" to 1/2" while the extraction gap was also increased from 1/4" to 1/2". The laser target to extractor distance was increased 30 cm to between 60 and 70 cm. This increased the ion drift time and, hence, the temporal ion pulse length.

Figure 1 is a schematic diagram of the experimental apparatus. The laser, laser target assembly, and Einzel lens, are all similar to those used in Ref. 1. Figure 1 shows a large Faraday cup that measures the ion current that comes directly out of the Einzel lens.


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Vacuum UV and soft x-ray optical emissions from electron impact on metals

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Spectrograms from 2200 to 20 Å of optical emissions produced by a simple lamp using fast (3–10-keV) electron impact on tungsten and tantalum targets are presented. The lamp dissipated up to 5 kW/cm² on the target surface, simultaneously cleaning the surface and generating bremsstrahlung in the soft x-ray region with 3-keV electron impact and longer wavelength transition radiation at the higher energy. In both the bremsstrahlung and transition radiation modes, the lamp emissions were of sufficient strength and reproducibility to qualify the two mechanisms as potential processes for use in a secondary standard light source. Calculated spectral distributions of transition radiation for normally incident electrons on tungsten, tantalum, and aluminum targets, with a viewing direction 45° from the normal, are also shown.

I. Introduction

Formidable experimental difficulties are encountered in investigations involving optical measurements in the vacuum ultraviolet and soft x-ray regions. One of the most serious problems is that all materials absorb, to some extent, at these short wavelengths. The performance of optics designed to operate in this regime often rapidly deteriorates with use, depending on the ambient atmosphere. Contaminants and/or photochemical residues of contaminants on surfaces make it imperative that frequent checks of the efficiency calibration be made. These checks can best be done by using a source of radiation with a known spectral distribution of intensity. At present, synchrotron radiation represents such a source in the VUV. It is a primary source of standard radiation since the radiation can be fully characterized using the known operating parameters of the machine. Other sources calibrated against such a primary standard become optical transfer standards. Any secondary standard should depend on a light-emitting mechanism characterized by a few simple, easily measurable parameters. If this is done, each secondary standard need not be individually calibrated (i.e., the mechanism is calibrated, not the lamp). Therefore, it is useful to have a lamp that operates in a hard vacuum and is easily scalable in intensity.

A lamp with these characteristics has been under study. It uses the electron impact on metals to produce the light. The electrons emerge from the cathode by both field emission and thermionic emission. It uses two different radiation mechanisms—transition radiation and bremsstrahlung—which predominately generate radiation in different wavelength regions.

Transition radiation, a surface effect, can be thought of as being produced by a collapsing dipole formed by the approaching electron and its corresponding image charge. When the electron disappears at the vacuum-metal interface, a pulse of light is emitted. The character of this radiation can be fully predicted by a semiclassical theory if the dielectric properties of the metal are known from optical reflectivity measurements. If the electron beam impinges normally on a thick target and the viewing direction is 45°, the spectral distribution of the radiation is reasonably simple. The theory of transition radiation1,2 is well established and experimentally verified.3

Transition radiation from metal targets is a long wavelength phenomenon. For optical frequencies greater than the metal plasma frequency, the metal is not effective in shielding the electromagnetic field of the electron once it is inside the metal surface. The collapsing dipole and annihilation of the incident electron at the surface are no longer a valid characterization. For normally incident electrons and an observation angle θ, there is a sharp decline in the intensity of transition radiation for wavelengths \( \lambda < \lambda_c \cos \theta \), where \( \lambda_c \) is the wavelength corresponding to the metal plasma.
**Ion beams from laser-generated plasmas**


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Space-charge-limited heavy ion beams have been produced by utilizing the plasma blowoffs generated by 20-MW bursts of 1.06-μ radiation from an active Q-switched Nd:Yag laser. Laser power densities near a modest $10^{11}$ W/cm$^2$ on solid targets generate thermalized plasma plumes which drift to a 15-kV grided extraction gap where the ions are extracted, accelerated, and subsequently electrostatically focused. The spatially defined ion beams are then magnetically analyzed to determine the charge-state content in the beams. Results are presented for the more significant amounts of charge states $Z \leq S$ contained in the beams formed from carbon, aluminum, copper, and lead targets. The extraction and acceleration technique preserves time-of-flight (TOF) information in the plasma drift region, which allows plasma ion temperatures and mass flow velocities to be determined from the Maxwellian ion curve TOF shapes for the individual charge species.

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I. INTRODUCTION

The concept of using directed laser-generated plasma plumes as a source of heavy ions for accelerator-based physics is an intriguing one. Among the potentially useful properties of these plasma plumes are (1) a copious supply of ions per laser pulse, (2) high stages of ionization, (3) short plasma generation times, (4) highly directional plasma plumes which can be directed along the accelerator axis when certain targets are used, (5) versatility in producing not only a multiplicity of charge states, but also a variety of nuclear species, since all solids can be used for plasma sources, (6) the “freeze” in the ion charge distribution during the plasma expansion with little recombination effects, (7) simplicity in generation since, in principle, only a solid target is required at high potential which is optically connected to the laser at ground potential, (8) generation of plasmas from solid targets does not require differential pumping and gas transport through an anode aperture.

Ions have already been extracted from laser-generated plasmas and have been put to various uses, but generally without appreciable consideration as a possible ion source for an accelerator. However, without modification the pulsed, explosive nature of the laser blowoffs is best suited for pulsed, high-current accelerators. Conventional pulsed machines, such as cyclotrons, require a higher duty cycle than can be currently attained with a laser ion source. Although both high power and moderately high repetition rates are currently available in both Nd:Yag and CO$_2$ lasers, our choice was a Q-switched 20-MW Nd:Yag laser, (Hologon model 5050Q), capable of generating 15-nsec-0.3-J pulses at a wavelength of 1.06 μ and a maximum repetition rate of 50 pps.

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II. APPARATUS

Figure 1 is a schematic diagram of the experimental apparatus. The laser beam from the laser H, is bent by a right-angle prism P and sent through a window W in the high potential terminal. The laser beam is reflected through an angle of 45° by a mirror M and directed through a 4-cm focal length lens L and a thin glass cover slip C placed immediately in front of the lens. The focused laser beam impinges on a 2 ½-in.-diam target disk T, which can be rotated by an electrically isolated stepping motor SM. The entire target assembly, including M, L, C, and T, is mounted on a translatable bench contained within a vacuum chamber. The laser beam produces a divergence limited spot of about 100 μ in diameter, corresponding to a power density near $10^{11}$ W/cm$^2$ at full laser power. (Note: The glass cover slip C plays an important role in protecting the laser vacuum optics, since coating of the focusing lens with laser-sputtered materials such as aluminum eventually creates a severe laser backscattering problem that can destroy both the lens and mirror. The protective cover glass is replaced as routine maintenance even though no deleterious effect of the sputtered material on the cover glass has been noted.)

The resulting plasma plume PL expands freely from the target to the extraction gap G, where positive ion extraction takes place across a ⅛-in. gap. Both the extractor electrode and the anode have ⅛-in.-diam apertures with 100-mesh 1-mil-diam tungsten grids placed across them. After high-voltage extraction the ions then immediately pass through two grounded 16 mesh, 6-mil-diam tungsten screens S, which ease the space-charge repulsion effect (i.e., beam blowup). The ions are focused onto a pair of collimating slits CS by a routine maintenance even though no deleterious effect of the sputtered material on the cover glass has been noted.)

The resulting plasma plume PL expands freely from the target to the extraction gap G, where positive ion extraction takes place across a 1-in. gap. Both the extractor electrode and the anode have 1-in.-diam apertures with 100-mesh 1-mil-diam tungsten grids placed across them. After high-voltage extraction the ions then immediately pass through two grounded 16 mesh, 6-mil-diam tungsten screens S, which ease the space-charge repulsion effect (i.e., beam blowup). The ions are then magnetically separated into the various charge states present in the beam.
energies for autoionizing lines from helium was also found. The results indicate that the autoionizing states of helium are perturbed by the coulomb fields of the slow moving projectiles. This perturbation may cause the intensity and energy variation as well as interference between closely lying autoionizing states.


C15 Radiation Spectra and Angular Distribution of Emitted Quanta for Planar Channeled Particles: Radiation of Single Particle. A. S. Kneifels and T. Knight, Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305. A method of calculating the radiation characteristics for the motion in an arbitrary one-dimensional potential is developed. Expressions for channelling radiation frequencies, polarization angles, and the number of emitted photons as functions of quanta angles, particle energy, amplitude of oscillations, and divergence in a plane parallel to the trapping crystal planes for any given harmonic number are found. The problem is treated in the classical approximation. Numerical examples of the application of the derived formulae for channelling in (H(1s),H(2s),H(2p)) directions of a Silicon crystal are given. The results are presented both for electrons and positrons. The comparison of the calculation results for two choices of continuum potential for positrons is also given.

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C16 NON-FEASIBILITY OF ELEMENTAL FORMATION IN THE SUPERHEAVY REGION BEYOND ABOUT 1452 -- S. M. Ayub, A-2, Bliss Apartments, 4/1, McNeil Road, Karachi/Pakistan. -- In the Superheavy Region, 110Z to 1452, the study shows that the electron orbits play a distinct role, whilst nuclei with double magic numbers are not spherical and the stability curves cannot give correct results and need amendments. The study further shows that by the projection of amended shell corrections carefully, the relativistic fission of 1452 nucleus gets to ~ 4.0 on single particle - shell modality. The valence electron of 1452 are: 2\(^{4}\) 6\(^{2}\) 74 85 86 87 The relativistic fission of the 5g electron orbit calculates to ~ 3.58 and of the 8p orbit to ~ 3.50. The electrons in these orbits can be considered as interfering with each other and of the 8p orbit collapsing into the nucleus. Consequently further elemental formation orbitals from 152 become impossible. The confident way of synthesizing superheavies is the existing Laser-Pellet technology under S.M. Fields.

C17 SCANNING FOR STABLE ELEMENTS IN THE SUPERHEAVY REGION -- S. M. Ayub, A-2, Bliss Apartments, 4/1, McNeil Road, Karachi/Pakistan. -- In the Superheavy region, due to unusual deformity of the nucleus, this study shows that many stability norms do not hold good. Double magic number nuclei for Neutrons and Protons are not spherical in (N(110),Z(110)) directions of a Silicon crystal are given. The results are presented both for electrons and positrons. The comparison of the calculation results for two choices of continuum potential for positrons is also given.

The discovery of Element 110Z by ion-collision methods and of Element 118Z and 126Z in the moon-rocks, meteorites etc., as mentioned.

C18 LOW keV Energy Ion-Molecule Collisions: D\(^+\)H\(_2\) -- J. STEVENS, N. VEDDER, R. ZELRI, JR., and E. POLLACK, U.C. of Calif.. -- D\(^+\)H\(_2\) collisions are studied at energies (E) from 1.5 to 3.5 keV and at scattering angles (\(\theta\)) corresponding to E\(_{\text{kin}}^2\) - 7.5 keV \(\text{deg}^2\). Peaks in the energy loss spectra are attributed to "quasi-elastic" and to electronically inelastic collisions.

While low energy losses in the "quasi-elastic" collisions imply that over most of the angular range the D\(^+\) is scattered by a single H atom in the H\(_2\) target. The experimental results suggest only a small amount of vibro-rotational excitation of the D\(_2\) occurs. The dominant small angle inelastic processes occur with threshold values of 9.4 and 12 kev, and are attributed to excitations of the H\(_2\) in agreement with the Franck-Condond principle.

*Work supported by A.R.O.D. and the University of Connecticut Research Foundation.

C19 A Study of D\(^+\)H\(_2\) at Low keV Energies. -- M. VEDDER, T. O'MEADHOGH, T. I. ALFAAREZ, B. E. PETERSON, R. HAYWOOD, and E. POLLACK, U.C. of Calif.. -- The D\(^+\)H\(_2\) collision system is investigated at small scattering angles (\(\theta\)) to study the threshold behavior of "quasi-elastic" ion-molecule scattering. The results show that at an energy (E) of 1.9 keV the collision is "elastic" for E\(_{\text{kin}}^2\) < 20 keV \(\text{deg}^2\), while the results at higher energies break away from the elastic limit at smaller E\(_{\text{kin}}^2\) values. 

At 3.0 keV the collision is binary (occurring with one H atom in the molecule) at all angles investigated. The energy dependence of the break away from elastic scattering is pronounced. The inelastic scattering in D\(^+\)H\(_2\) shows a single dominant channel (Q \(\sim\) 13 eV) with a reduced cross section peaking at E\(_{\text{kin}}^2\) \(\sim\) 20 keV \(\text{deg}^2\).

*Work supported by A.R.O.D. and the University of Connecticut Research Foundation.

C20 H(2s) Atom Formation in H\(^+\)-H(1s) and H\(^+\)-H(1s) Collisions. T.J. MORGAN, J. STONE, and R. MUTO, Department of Physics, Wesleyan U.-- We have measured cross sections for metastable H(2s) atom formation in 1.0-92 keV H\(^+\) and H(1s) collisions with H(1s) and CH\(_4\) targets using a time-of-flight technique. Fast H(2s) atoms formed by collisions in the target were detected downstream using electric field, Rutherford and Lyman -- a photon counting techniques. For H\(^+\)-H, low energy data are in agreement with multi-state molecular treatments of the collision. Above 75 keV the data are in accord with the Born approximation cross sections. For H\(^+\)-H, all theoretical treatments of the collision are in poor accord with experiment. However, for energies greater than 40 keV the measured cross sections exhibit an \(E^2\) energy dependence, in agreement with theoretically predicted asymptotic behavior. Significant differences exist between the present results and previous measurements. Data will also be presented for a molecular hydrogen target.

C21 Magnetic Analysis of Laser Generated Plasmas. -- L. E. G. ARMY, M. M. HUGHES, R. J. ANDERSON, J. P. ROSENFELD, and C. K. MONKA, University of Arkansas. -- Laser pulses of 15ns duration (FWHM) and 25MW power from a Q-switched Yag laser are focussed to power densities of \(10^{14} \text{W/cm}^2\) on solid targets of Alumnum, Carbon, Copper, Lead and Tungsten. The resulting laser-blowoff plasma is allowed to drift distances of 15cm and 30cm before it is extracted and focused into a 15kV heavy-ion beam by an einzel lens. Subsequent magnetic analysis of the ion beam separates ion charge states up to \(Z = 46\). The ions are collected in an array of Faraday cups designed to obtain simultaneous...
Optical Emissions in the VUV from 2-keV Electron Impact on Tungsten, T. A. Hauser and R. H. Hughes, University of Kentucky.—A novel optical transfer standard lamp for the vacuum ultraviolet is being developed using bremsstrahlung and transition radiation from an electron impact on metal targets. The source depends on thermionically assisted high-field electron emission from a knife-edge cathode. The optical emissions have been quantitatively studied from 4000 Å to 1100 Å. Below 2000 Å the optical spectra is dominated by bremsstrahlung. The photon yield per unit wavelength interval increases as the wavelength decreases. Strong emissions are observed from W targets at to at least 400 Å where it becomes difficult to separate first order spectra from specular reflection from the grating in our Sear-Namiboka spectrometer. The shortwave bremsstrahlung cutoff is near 6 Å for 2-keV impact.

*Research supported by NASA, Grant NGS 7106.

SESSION JG: INTERMEDIATE ENERGY–THEORY II
Thursday morning, 28 April 1979

C. B. Dover, presiding

JG1
Back Scattering in the Glauber Context. P. A. Kazans, New College of the USA, Sarasota. Elastic scattering into back angles is examined in the context of the Glauber approximation. The ultimate goal is to determine to what extent the back angle approximation can provide information in a simple fashion about nuclear structure and hadron–nucleon interactions. Here the potential scattering model is used. Two forms of the back scattering approximation are discussed. They are tested by calculating with functional forms that arise as optical potentials in hadron–nucleon scattering. The results of the calculations will be presented and used to provide a zeroth order assessment of the usefulness of the back angle approximation.

JG2
Plane Exchange Contributions to Nuclear Reactions at Large Momentum Transfer. J. KALLEN and P. C. GUSOLOT, Univ. of Virginia.* We have examined proton elastic back scattering on light nuclei A = 2, 3, 4, and the reaction \( p^+ + \text{He} \rightarrow \text{He}^+ + \text{d} \) at intermediate energies \( E_p = 100-800 \) MeV. In such reactions where one or several are transferred from the target nucleus it is common to consider the other target nucleons as passive spectators. This approach works at low angles and small recoil momenta but beyond that regime the spectator model is a less fortunate approach. Little remedy is provided by correcting for scattering effects of the DMBA type. We find that characteristic features of the data at higher energies can be understood in terms of pion exchange contributions which are qualitatively assessed in terms of the subprocess \( p^+ + \text{A} \rightarrow \text{p} \rightarrow \text{He}^+ + \text{He} \) for \( p^+ + \text{He}^+ + \text{He} \rightarrow \text{p} \rightarrow \text{Ne} + \text{d} \). The need for high nucleon momenta are very much reduced for such reaction mechanisms.

**Supported by the U.S. Department of Energy.

JG3
Short Range Correlations and the Nuclear Momentum Density Distribution for \( { }^{14} \text{C} \).* J. W. VAN Orden, M. K. Ranahe, and W. Truef, U. of Maryland, College Park.* The leading-order correlation corrections to the independent particle shell model (IPS M) momentum density distribution for \( { }^{14} \text{C} \) are calculated using the Brueckner theory of finite nuclei. The Radial functions are calculated using a Reid "soft core" 3D nucleon–nucleon interaction potential with harmonic oscillator starting wave functions. The correct shell model starting energies and Pauli corrections. The short range correlations are found to significantly modify the IPSM momentum density distribution for low momenta and to dominate it for high momenta.

*Supported by the U.S. Department of Energy.

JG4
High Spin Unnatural Parity Excitations in the \( (e,e') \) \((pp')\) and \( (e,e') \) Reactions.* F. Petrovich, Florida State U, W. G. Low, U. of Missouri, K. A. Lindgren and W. J. Gerace, U. of Massachusetts, G. Walker and A. D. Bacher, Indiana U., R. Sollano and R. A. Poliessen, R. A. Badeau, and J. E. Bielecky and J.E. Wise, U. of Virginia. The available experimental data for the excitation of high spin unnatural parity states in the \( (e,e') \), \((pp')\), and \( (e,e') \) reactions now extends to levels in nuclei ranging from \( { }^{12} \text{C} \) to \( { }^{40} \text{Ca} \). The transition amplitudes corresponding to excitation of these levels have particularly simple forms and definite information about the models used to describe the reactions can be obtained by comparing theoretical calculations with the experimental data. The results of such a study will be discussed.

Supported in part by the NSF and D.O.I.

JG5
Deep Inelastic Electron Scattering from \( { }^{56} \text{Fe} \).* R. M. Altemus, A. Capolla, J. S. Coatsworth, R. R. Whitney and J.E. Wise, U. of Virginia. Deep inelastic corrections for vector momentum transfers from 200 MeV to 150 MeV. The ranges of electron energy loss include the quasi–elastic peaks and extend into the region of meson production. Results on the corrections to the Born approximation in the given region of angles, transport, and energies will be presented. Deviations from the simple impulse approximation and the meson exchange contributions to the reaction are noted.

*Supported by the U.S. Department of Energy.

JG6
Radiative Correction in Deep Inelastic Electron Scattering.* R.M. Altemus, A. Capolla, J.S. Coatsworth, R.R. Whitney and J.E. Wise, U. of Virginia. Radiative corrections for deep inelastic electron scattering on \( { }^{56} \text{Fe} \) at incident energies of several hundred MeV, angles of \( 90^\circ \) and \( 160^\circ \) and total energies as low as \( 40 \) MeV will be presented. The peaking approximation, with various forms for the equivalent radiator, and the "exact" calculation for the elastic tail will be discussed. Experimental and theoretical target thickness dependencies will be shown.

*Supported by the U.S. Department of Energy.

JG7
Elastic p–d Scattering in Spin Channels at Intermediate Energies. J. James A. Sromek, Univ. of Maryland, College Park. A Glauber theory calculation of p–d elastic scattering in spin channels is presented. D state admixture, CN + Breit frame transformation of \( n^\ast \) amplitudes, and intermediate D-state corrections are included. The input p p–amplitudes are determined from a phase shift analysis of Hoshiyaki and not varied. For consistency the p–n amplitudes are taken from p–nucleus elastic scattering fits using the aforementioned p–p amplitudes.

*Supported by the U.S. Department of Energy.
device using a short pulse Nd: glass laser is proposed. A light pulse propagates in a plasma with group velocity \( c(1 - r^2/w^2)^{1/2} \) and the ponderomotive force of the photons leaves behind a train of plasma waves. Each wave has a phase velocity same as the photon group velocity. Such plasma waves trap electrons and are efficient accelerators of electrons to high energy. Either by preacceleration or by density gradient, it might also be possible to accelerate ions. The maximum energy electrons can gain is \( N = 2e(c w_0^2 / w)^{1/2} \) (where \( w_0 \) is the laser frequency and \( w \) is the plasma frequency) for ions. Wave breaking sets a limit on the electrostatic field at \( E = n c w_0^2 / e \). With a laser light focused to 10^18 W/cm^2 and plasma of density \( 10^{18} \) cm^-3, it will take 1 cm to accelerate electrons to 1 GeV with electrostatic field of 10^8 V/cm through this mechanism. Computer simulations on the 2-D relativistic electromagnetic code have demonstrated this concept and confirm the scaling law for \( N \) at least up to \( (w_0/c)^2 \approx 40 \). Applications to pulsars and cosmic rays are also suggested.

*Work supported by NSF.

**Hit 3** Transport Coefficients in Halogen-Nitrogen and Halogen-Same Gas Mixtures. K. N. NAGBAR, S. K. HARTR>, N. K. BODAS, C. K. POLYAI, and L. H. ZINKE, University of Missouri-Rolla.--Using the method developed by Grunberg, we have measured the attachment coefficient and electron drift velocities for several halogen-containing gas mixtures. Specifically, results have been in N_2, NH_3, Ar, and CF_4, for the range of E/N from 1 to 40 Td (1 Td = 1.7 \times 10^{-17} V cm^-2). Halogen concentrations were varied from 0.1% to 1.0%, with total gas pressures of 10 Torr to 100 Torr. Calculations of the rate coefficient have been made from our data and compared to the results of other researchers.

*Supported in part by ARPA/ONR and Los Alamos Scientific Laboratory.

*Present address: Dept. of Electrical Engineering, Univ. of Liverpool, Liverpool, England.

**Hit 4** Electron Transport Coefficients in CO and CO_2-Mixtures of Laser Interest. R. A. STERN and K. N. NAGBAR, University of Missouri-Rolla.--Transport coefficients for electrons in CO, and CO_2-mixtures have been measured at total pressures ranging from 10 torr to 200 torr and over an E/N range of 40 Td to 220 Td (1 Td = 1.7 \times 10^{-17} V cm^-2). At low E/N where attachment in pure CO-1% is very small, the attachment coefficient \( N/N \) has been measured using an integrated charge method. At higher E/N the spatial current growth has been monitored to obtain both attachment and ionization \( N/N \) coefficients. In addition, temporal analysis of the electron transient waveform has yielded drift velocities in these gases. The results are compared with theoretical calculations and with existing experimental data.

*Supported in part by Los Alamos Scientific Laboratory.

**Hit 5** Time-of-Flight Analyses of Magnetically-Separated Charge States of Ions from Laser-Produced Plasmas. C. J. WANG, K. J. WILHELM, S. H. KOH, and D. L. GILES, University of Illinois.--A laser-produced plasma was simultaneously ionized and extracted into a field-free region. The ions were then allowed to drift, and the ions were then extracted and focussed by an einzel lens onto a magnetic analyzer which produced charge-state assignments. Each charge state was analyzed by the time-of-flight technique. Excellent fits to Maxwell-Boltzmann distributions were observed and the plasma temperature and flow velocities were calculated. Non-common temperatures for ions of different charge states from single plasmas are indicated.

*Work supported by AFSOR Contract No. F49620-76-C-0007.

**Hit 6** Finite-Length Theory of Collectively-Free-Electron Lasers. S. JOHNSTON, Columbia U.--The small-signal gain of a free-electron laser operated in the stimulated Compton mode is derived without limitation on the density of the electron beam employed. Expansion of the exact result in powers of the linear susceptibility \( \chi \) reproduces the vacuum gain formula, and shows that the leading plasma correction causes a slight enhancement in the vacuum gain. The theory also generalizes past work by including a static guide magnetic field and an arbitrary distribution of beam momenta; the principal assumption is small gain in the available length (i.e., a recycled system). For deaser beams \( (|\chi|/1) \), it is shown that stimulated Compton scattering persists in a finite-length system, and that the Compton gain can easily rival the finite-length Rayleigh gain in which is derived for comparison. The possibility of an x-ray laser operated in this new regime (plasma-modified Compton effect) is discussed.

*Supported by AFSOR grant F49620-75-C-0055.

**Hit 7** Ablative Accelerator Designs for Light Ion Beams. J. R. ADAMS and J. S. HOENIG, U.S. Naval Research Laboratory.--Light ion beams are of interest as an energy source for ablative-driven pellets for inertial confinement fusion. The ion beam deposits its energy in a much thicker region of the ablating material resulting in more energy in the material being blown off at a lower velocity and hence a lower efficiency of transfer of energy to the payload. One way to overcome this is to put a heavy tampering material at the outer edge of the ablating mass. The mass of this tampering material must be chosen so that the plasma peaks for a given ion beam will occur in the ablating material. At quasi-geometrical one dimensional hydrodynamic code has been developed which allows as to treat interfaces of materials while maintaining the desirable features of fluid-dynamical mode. We present results for calculations of proton beams absorbed in a sandwich layer of gold and plastic. We investigate the optimum thicknesses of the gold and plastic layers to provide the best energy transfer and maximum velocity obtained for the accelerated payload.

*Work supported by the U.S. Department of Energy.

**Hit 8** Intense Relativistic Electron Beams Expanding into a Field-Free Vacuum. F. MURRAY, D. FERNSCH, J. SMITH, and W. O. DUGGAN, North Carolina State Univ., Raleigh, N. C.--An intense relativistic electron beam produced in NCSU's 7 cm diode (0.5 MeV, 70 kA) is fired through a hole in the anode plate into a field-free vacuum. The transmitted beam was observed as a result of its own self fields. A principle diagnostic employed was blue cellophane film which is calibrated to give current density as a function of change in transmission coefficient for red light. The transmission coefficient is determined on an optical microdensitometer which has been modified to accommodate the laser as its light source. The calibration of the density change to the current in transmission agrees with experimental error with a previously published value at much lower order of operation. Preliminary results will be presented which show the radial beam profile as a function of axial position.

*Supported by AFSOR Contract No. F49620-76-C-0007.

**On a sabbatical leave from U. of Scranton, Scranton, PA.**
measurements of the $Z = +1$ to $Z = +6$ ion currents. Time-of-flight analysis of the individual ion current signals yields estimates of the ion flow velocities while absolute measurements of the charge collected in each Faraday cup gives the number of ions in a particular charge state.

C22 NEHD: Magnetoelectric Hydrodynamics*. K. T. LU, Argonne National Laboratory, Argonne, Illinois 60439. -Conspicuous effects of the new stark potential on highly excited and ionized atoms have recently been realized. In this light, it is suggested here that NEHD programs (as customarily applied to the study of coal or gas burning or astrophysical phenomena) should really be called NEHD instead. Namely, not only are the magnetic properties important, but the electric properties - induced by the thermal motion of the elements in the presence of strong magnetic field - also can be significant for high and low temperature plasmas. *Supported by the U. S. Department of Energy.


C23 Atomic and Molecular Studies at the NSLS.* J. B. A. Mitchell, J. R. Grover, and R. R. Klemm. Brookhaven National Lab.—An apparatus for the study of atomic and molecular systems using the National Synchrotron Light Source is under construction. Designed to offer optimum versatility it will be available for use by outside scientists when the NSLS commences operation early in 1981. A variety of vacuum components and ancillary hardware will be provided together with a high flux, medium resolution, normal incidence monochromator and associated beamsplitter. Photon fluxes of 1013-1014/sec in the wavelength range 2000-3000 Å with 0.25 Å resolution should be available from the instrument. Early projects by in house staff will include photoionization mass spectrometry of radicals, molecules, and clusters produced in a helium seeded supersonic nozzle source. Rearrangement of the equipment for molecular beam sampling of flames will be discussed.

*Research performed under the auspices of the U. S. Department of Energy.

C24 Multiplet Splittings in the 3d Configurations. A. F. A. BETHA, University of Wisconsin-Green Bay.—A comparative study of the energy levels of transition metal ions with $d^2$ configuration is carried out. The importance of various interactions in the calculation of energy levels is examined particularly when the half filled shell the spin-orbit interaction does not have a first order effect so that the overall term splittings are found to be small. The role of spin-other-orbit and spin-spin interactions is examined. For 3d II these are experimentally measured four quartet and eight doublet terms which split into 31 levels. The 11 term description the electron-electron interactions and the 19 multiplet splitting determine the spin dependent interactions. The calculated energy level diagrams are found to be in good agreement with the experimental values.

C25 Relativistic Equation-of-Motion Approach to Transition Processes in Many-Particle Systems.* K. N. Huang, Univ. of Notre Dame. —The relativistic equation of motion for transition matrices is formulated using techniques of quantum field theory. To reduce the equation of motion to a tractable form which is appropriate for numerical calculation, we employ a graphical method to resolve the complications arising from the antisymmetrization and angular momentum coupling. This reduction procedure leads to a system of coupled radial equations which can be solved numerically. The relativistic equation-of-motion method allows an ab initio treatment of correlation and relativistic effects in both closed- and open-shell many-particle systems.

*Supported in part by the National Science Foundation.

1. N. Huang, Rev. Mod. Phys. 51, 215 (1979)

C26 Use of an Interactive Computer for Parameter Estim in Curve Fitting. C. K. Manka, J. P. Rosenfeld, R. J. Anc and R. H. Hughes, University of Arkansas. —Parameter estimation for nonlinear equations is carried out using an interactive computer and CRT display. The data and theoretical functions are presented simultaneously. The program gives an opportunity to adjust parameters followed by a presentation of the "fit." The goodness of fit is judged visually, but a fit may be obtained after each parameter adjustment. Operator is used to quickly develop and the method can be very fast. Experiments are presented.

C27 Progress Toward Measurements of Dielectronic Recombination in Cs*. G. P. LAFERTY and J. L. KOLL, Harvard-Hastings Center for Astrophysics.—An extended electron beam-ten beam experiment to measure dielectronic recombination will be described. Initial measurements to determine the recombination of triply charged carbon ions have begun with electrons energies just below the 2s+2p excitation threshold near 6 eV. Two products of individual dielectronic recombination were detected in coincidence—the recombined ion and the photon from the stabilizing transition. The recombined ions are detected directly using conventional charge state analysis or indirectly using field ionization techniques. Experimental considerations will be outlined and progress reported.

*Work supported by the Smithsonian Institution under the Research Awards Program and the Fluid Research Fund.

C28 Dielectronic Recombination of Electrons with Hs* Ions. G. G. BONDI and J. N. BAGDADIAN, U. Pittsburgh.—At energies below 1 eV, dielectronic recombination in $e + Hs$ collisions proceeds primarily through the $(1s)^2 1s^2$ and $(1s)^2 1s^3 S$ states of $Hs$, for which the potential curves and autodetion rates have been calculated by Bobo. These states can be formed directly, through the excitation of the target electron, or indirectly, through the formation and predissociation of an excited vibrational level of the hydrogen state manifold. A unified treatment of the direct and indirect recombination processes is described, and is applied to this example. Interference between these two modes is possible, and may be important for the recombination of ions in excited vibrational states. The theoretical approach is related to the multi-channel quantum-defect theory of Giusti-Baron and the results are compared with the data obtained in inclined-beam and merged-beam experiments.

*Supported by the National Science Foundation (Grant N179-00997).


C29 A Polarized Electron Source for Use in Atomic Physics. R. J. CELOTA, D. T. PIERCE, AND G.-C. WANG. National Bureau of Standards.—A modular source of spin polarized electrons has been developed, based upon photo-emission from negative electron affinity GaAs using circularly polarized light. Its salient features include electron currents of micro-amperes, a polarization of 43%, rapid, external polarization reversal, high brightness and a narrow energy distribution. The operating characteristics and principles will be described and illustrated by examples of its use in the study of spin dependent electron scattering resulting from both $L$- and $M$-coupling and the exchange interaction.

Excitation of the $B^2\Sigma^+_u \ (v' = 0)$ State of $N_2^+$ by 0.1- to 6.0-keV Proton Impact on $N_2$

R. H. Hughes, R. Carter, and K. B. Knowlton

Department of Physics, University of Arkansas, Fayetteville, Arkansas 72701

Cross sections for excitation of the 3914-Å (0, 0) band of the $B^2\Sigma^+_u \rightarrow \chi^2\Pi^+_g$ transition of $N_2^+$ by proton impact on $N_2$ have been determined in the impact range from 100 eV to 6 keV. Cross sections for excitation of the $B^2\Sigma^+_u \ (v' = 0)$ state are inferred from these measurements. The cross sections decrease by 2 orders of magnitude in a near-monotonic fashion in this energy range. Comparisons are made with total electron capture.

INTRODUCTION

Proton aurorae are characterized by intense $N_2^+$ emission and prominent hydrogen Balmer emissions [Eather, 1967]. Doppler shift measurements on the Balmer emissions indicate that the radiation is primarily from $H$ atoms with kinetic energies below 10 keV. Rocket soundings during aurorae give ion spectra which support this concept of low-energy excitation [Birely and McNeal, 1971]. This paper reports the first phase of an investigation of excitation processes involved in low-energy proton and $H$ atom impact on $N_2$, namely, the excitation of the $N_2^+$ 3914-Å band emission by 0.1- to 6.0-keV proton impact on $N_2$.

In this energy range, electron capture is a dominant reaction which converts a large fraction of auroral protons to neutral atoms [McNeal and Birely, 1973]. Thus excitation by $H$ atom impact on $N_2$ is likely to be more significant than $H^+$ at these energies despite the fact that the cross sections for $H$ atom impact are smaller [Birely, 1974].

Laboratory data are available for $N_2^+$ 3914-Å band emission down to a low-energy limit of 1 keV for both $H^+$ and $H^0$ impact. However, many of the data have been obtained with the use of accelerators having radio frequency ion sources which have plasma energy anomalies [Cook et al., 1962]. It is possible to underestimate the energy of beam particles by hundreds of electron volts, depending on the ion source operating parameters. An error of this magnitude is significant when cross sections change rapidly with energy and when the ion source plasma energy is an appreciable fraction of the total beam energy. Further, Hoffman et al. [1975] argue that some of the beam current measurements are suspect.

$N_2^+$ molecules in the $B^2\Sigma^+_u \ (v' = 0)$ state are formed by the reactions

$$H^+ + N_2 \rightarrow H^0 + N_2^+ \quad (1)$$
$$H^+ + N_2 \rightarrow H^+ + N_2^+ + e \quad (2)$$

The experiment of Wehrenberg and Clark [1973] suggests that the electron capture reaction (1) dominates at low energies (below 9 keV). This is intuitively reasonable. The energy defect for the direct double-electron excitation reaction (2) is 18.8 eV, while the electron-capture excitation reaction (1) is 5.2 eV. It is characteristic of these reactions that the probability of occurrence of a reaction with the larger energy defect will maximize at a higher impact energy. (The energy defect is the net change in the internal energy of the collision system.)

APPARATUS AND PROCEDURE

Figure 1 schematically displays the experimental arrangement. The duoplasmatron ion source was similar in design to that of Moak et al. [1959]. The protons were extracted from the ion source by applying 2500 V across the extraction gap. The beam was focused by an Einzel lens system. The protons were magnetically selected and sent through a single potential gap that determined the final beam energy. The protons then entered a differentially pumped collision chamber through a grounded 1-inch by 1-inch aperture. The collision chamber also acted as a Faraday cup. The 1-inch opening to the Faraday cup was guarded by an electron repeller plate ½ inch directly in front of the Faraday cup opening. The repeller plate also had a 1-inch diameter aperture. A maximum beam current...
Halides. G. R. and Khonna, Cohen, and co-workers. The maximum conductivity value and is in good agreement with the maxima of TTF grown and studied. The temperature conductivity measurements will be presented, along with structural results of room-temperature XRD studies. The conductivity of TTF is unusual in that the "metal-insulator" transition shows a 40K hysteresis upon temperature cycling.

GI 12 Low-Temperature Metallic Behavior and Resistance Molimn in the New Organic Conductor HMTSF-TCNQ. A. N. Bloch, D. G. Conan, K. Becho, A. O. Kohler, T. J. Kettermacher, R. E. Plue, R. Banks, and T. E. Phillips, Johns Hopkins U. -- We report a new quasi-one-dimensional organic conductor which behaves as a metal throughout the conventionally accessible temperature range. The charge-transfer salt HMTSF-TCNQ displays the largest high- and low-temperature conductivities ($\sigma$300K) ~ 20000 $\Omega^{-1}$ cm$^{-1}$, 0(1.5K) ~ 10000 $\Omega^{-1}$ cm$^{-1}$) of any known organic substance. The resistivity passes through a broad minimum in the range 45-75K; associated with this behavior is a strong anomaly in the thermoelectric power. The microwave conductivity at 10 GHz agrees precisely with the d.c., and the microwave dielectric constant is large and negative throughout the temperature range. Crystallographic, magnetic, and thermodynamic data are also presented. Our findings are consistent with the theoretical result that fluctuations can enhance the resistivity of a one-dimensional metal as T$^2$.

Supported by the Advanced Research Projects Agency, Department of Defense.

A. P. Sloan Foundation Fellow.

GI 13 Measurements of the Electric Susceptibility and DC Conductivity of Crystalline TTF-TCNO, J. P. Ferraris, and T. F. Finnegan, National Bureau of Standards (Wash., D.C.) -- Crystals of TTF-TCNO grown under an inert Ar atmosphere from multiply gradient-sublimed TTF and TCNO in quadruple-distilled CH$_2$NO solvent via the U-tube diffusion technique. The microwave conductivity along the b-axis of long (~4 mm, thick (~0.1 mm) crystals has been measured between 5 and 300 K via a cavity perturbation technique and interpreted consistent with the skin-depth formalism of Kohn and, more recently, by Co., and Co.,. The microwave resistivity observed is about 40-50 times the room temperature value and is in good agreement with the maxima inferred from dc conductivity data. In the insulating state, the dielectric constant along the b-axis near 10 K is greater than 10$^3$ at 9.5 GHz. A contactless method for determining the high-conductivity-axes via microwave measurements will also be discussed and some of the difficulties inherent in the cavity perturbation technique will be reviewed.

GI 14 MICROWAVE CONDUCTIVITIES OF TTF-TCNO, W. N. Hardy, A. J. Bertlinsky, and L. Weller, University of British Columbia: We have developed a contactless method for measuring the microwave conductivities of small, needle-like crystals in which the sample acts as the center conductor of a weakly coupled coaxial transmission cavity. Advantages of the method are: a) Even for conductivities equal to that of copper (~10$^5$ $\Omega^{-1}$ cm$^{-1}$) almost all of the cavity loss is due to the longitudinal conductivity of the sample alone, b) the sample geometry allows the method to be analyzed in a fairly rigorous fashion, and c) it is thought that the method cannot give conductivities higher than the true values, even in the presence of high electrical anisotropy. This last characteristic is of particular importance with regard to the organic salt TTF-TCNO where four-probe d.c. methods are problematic because of extreme electrical anisotropy. We have applied the method to a number of TTF-TCNO crystals grown at UBC whose dimensions gave fundamental resonances in the 10 to 30 GHz range. It was found that the shapes of the vs T curves were almost identical to D.C. conductivity results obtained at UBC on crystals of similar origin.

GI 15 Electron Paramagnetic Resonance in Anisotropic Conducting Samples with Application to TTF-TCNO, Arnold N. Kahn, National Bureau of Standards, Washington, D.C. 20234. -- Shiny currents in a long conducting anisotropic solid, of rectangular cross-section, oriented parallel to an applied magnetic field have been studied. The solution for the penetrating field has been found in the form of a Fourier series, and the average dissipated power and average energy stored have been calculated. The changes in resonant frequency and quality factor of a microwave cavity into which a sample has been introduced are expressed in terms of the stored energy and dissipated power. Application is made to the EPR absorption due to spins uniformly distributed through the sample, as outlined by Bloembergen. The geometric resonance line is similar to that of the infinite plate, but the peak line anisotropy is reduced as sample dimensions are decreased. For small samples of TTF-TCNO the analysis predicts a transition from an isotropic line at room temperature to the skin-depth limited line at 5K, with a maximum anisotropy at intermediate temperatures. Inclusion of displacement current does not modify this conclusion.

THURSDAY MORNING, 3 APRIL 1976

GJ 1 Production of Atomic Deuterium in the n=3 States by Electron Bombardment of D$_2$, C. B. Richardson, B. P. Gilstrap and R. H. Hughes, Univ. of Arkansas. -- Measurements of fine structure in the n=3 states of deuterium by the microwave-resonance optical method of lamb have yielded, through the signal strengths, information on the relative rates of production of 3s, 3p, and 3d atoms when D$_2$ is bombarded by electrons. We have also examined the electron-energy dependence near threshold of the microwave signal strengths and total light received through a Balmer-Alpha interference filter. Anomalously sharp structures (0.01 eV) are observed in both.

GJ 2 Thermomagnetic Force in the Waldmann Limit. Lorne A. Davis, Gases At Low Temperature, Magnetic dependence of the thermal force on a disk has been measured for the polyatomic gases N$_2$, HD, CO, and CH$_4$ for conditions approximating the Waldmann Limit, while the mean free path is much larger than the disk radius.
Destruction of fast H(2s) atoms by collisions with He, Ar, H₂, and N₂

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Absolute cross sections for the destruction of hydrogen metastable atoms [H(2s)] have been measured for impact on He, Ar, H₂, and N₂ in the energy range from 20 to 120 keV. Cross sections have also been measured for the collisional ionization of H(2s) by impact on H₂ in this same energy range. The analysis of the collisional destruction of H(2s) includes electron capture into unbound states of the negative ion with subsequent loss of the excited state as one of the quenching mechanisms in this energy range. Collisional ionization (direct electron loss) of the metastable projectile accounts for most of the remaining destruction. Within experimental error, collisional ionization and electron capture can entirely account for the destruction by impact on He. Additional quenching mechanisms are required for impact on the other targets. It is found that about 70% of the noncapture destruction is accounted for by collisional ionization in these cases. The results for destruction by impact on the molecular gases, N₂ and H₂, appear to be adequately explained by the inclusion of dipole-quadrupole electric-field quenching as the third mechanism.

I. INTRODUCTION

The destruction of fast metastable hydrogen by collisions with gas targets has been the subject of several previous experimental investigations in the energy range of the present experiment. These include the work of Dose et al. (2–60 keV), Gibboby et al. (10–30 keV), and Krotkov et al. (0.25–30 keV).

Collisional ionization (direct electron loss) has been recognized as a major source of destruction. Bates and Walker have formulated expressions using a classical impulse approximation which can be used to estimate collisional electron loss by fast excited atoms. Cross sections for this process have been measured by Gilbody et al. (10–30 keV) and Hughes and Choe (20–120 keV). The experimental evidence indicates that caution must be exercised in the general use of these expressions at low energies, possibly due to approximations used in simplifying the integrals.

Hughes and Kisner have suggested that electron capture is an important process in the quenching of excited states. Bates and Walker have pointed out that the field of the electron in the excited hydrogen is not well shielded by the field of the proton. Conversely then, the field of the proton is not well shielded by the electron and therefore electron capture should be an important process in the destruction of excited states. Cross sections for formation of stable negative ions are small. Hughes and Choe point out, however, that electron capture can still be an important destruction mechanism since electron ejection from unstable negative-ion states is a probable process.

The "separated-particle" picture of the excited hydrogen atom, of course, neglects the polarizing field of the bound partner in the collision interaction. The electric fields produced during the collision can quench the excited state by inducing transitions to bound states, as well as unbound states, of the hydrogen projectiles. These can be thought of as transitions produced by the interaction of the hydrogen dipole with the electric field moments of the target. The target may have permanent electric moments or may have moments induced by the electric field of the fly-by hydrogen projectile.

II. APPARATUS AND EXPERIMENTAL TECHNIQUE

The apparatus is the same as that described by Hughes and Choe. A magnetically analyzed proton beam is sent through a differentially pumped neutralizing chamber, emerging into an evacuated chamber containing a long-path, weak, transverse electric field designed to sweep the remaining protons from the beam but not to appreciably deplete the H(2s) content in the beam. After leaving this field, the beam is composed almost entirely of H(1s) and H(2s) atoms.

Before entering the differentially pumped collision chamber, the beam passes through a series of electrodes designed to apply a pulsed short-path longitudinal electric field sufficient to quench the H(2s) atoms. With the pulsed quench field off, the density of H(2s) atoms in the beam after passing through the collision chamber is

\[ n_{\text{off}} = n_{\text{on}} (1 - \sigma_{\text{L}} \rho L) + n_{\text{ion}} \rho L, \]  \hspace{1cm} (1)

where \( n_{\text{on}} \) is the density of H(2s) atoms at the entrance to the collision chamber, \( n_{\text{ion}} \) is the density...
E-1 Vibrational Excitation of N$_2$, CO, and N$_2$O by Low Energy Electrons. S. P. Wong and G. J. Schulz, Yale U. - A cross-over electron-beam resolution 22-35 meV is used to study the absolute differential vibrational cross sections to v=1 and v=2 of the ground state of N$_2$, in the energy range 1-30 eV. Two new broad resonant peaks are observed near 8 eV and 13.3 eV respectively, and they are interpreted as shape resonances. In CO, which is isoelectronic with N$_2$, an additional mechanism was found. Sharp structures have been observed in the elastic and vibrational cross sections at energies coincident with the v=0, 1 and 2 levels of the a$^3$Σ state of CO. The large electric dipole moment (1.38 D) associated with the a$^3$Σ state appears sufficient to bind temporarily the incoming electrons at or near the top of the potential well. In N$_2$O, the vibrational excitation via the 3.3 eV 3Σ resonance is found to consist of four series of modes (n=0, 1, 2, 3) associated with the 3Σ state of N$_2$O. 

*Work supported by NSF and by DNA through ARCO.


E-2 Vibrational and Rotational Excitation of CO, by Low-Energy Electrons** - M. D. Johnson and W. B. F. Johnson, Physics Department, Rice U. - In electron-CO elastic collisions, relatively large 0+1 rotational-excitation and 0-0 rotational-inelastic cross sections arise from the (transient) dipole moment which accompanies transitions between the ground state (000) and the bending mode (010). A model in which the electron is scattered from a "dipole" is shown to yield a total scattering cross section under restricted circumstances. Cross sections for transitions involving the bending mode 010 will be presented and discussed.

*Supported in part by the U.S. Atomic Energy Commission, and Robert A. Welch Foundation.

**Fannie and John Hertz Foundation Fellow.


Electron impact dissociative ionization of CO$_2$ has been studied with an apparatus containing crossed molecular and pulsed electron beams. The structure is observed in the O$^+$ curve. The electron impact dissociative ionization of CO$_2$. The spacing between the features observed is approximately 0.08 eV which is consistent with their originating through predissociation of the B$^1$Σ state of CO$_2$.

*Research sponsored by the U.S. Atomic Energy Commission under contract with the Union Carbide Corporation.

**Graduate student, University of Tennessee, Knoxville, Tennessee 37916.

E-4 Vibrational Excitation and Transmission Spectroscopy in Hydrogen Halides. I. P. Tsvetaeva, I. N. Nemer and G. J. Schulz, Yale U. - Vibrational excitation near threshold has been observed in HC$_2$(v = 1, 2) and DCl(v = 1, 2, 3) with a trapped-electron apparatus. The vibrational cross sections rise steeply near threshold and levels off above 60 meV above threshold. The magnitudes of these cross sections have been measured (about 10$^{-15}$ cm$^2$ for HC$_2$(v = 1) and are interpreted in terms of resonant contributions. These large vibrational cross sections produce structure in the transmission spectra of HC$_2$, HBr and their isotopes. Additional features are attributed to Wigner cusps.

*Work supported by ONR.

E-5 Excitation of H$_2$ by Low-Energy Electron Impact** - J. Watson, Jr., J. N. Adams, and R. J. Anderson, University of Arkansas. Optical excitation functions for fourteen spectral lines of the neutral H$_2$ spectrum were measured for incident electron energies in the range 0-200 eV. The lines were observed at a spectral slit width of 80 and were assigned to corresponding vibrational and electronic transitions using the wavelength tables of Dieke. They include the singlet transitions na + 2a, m + 2b and m + 2c, and the triplet transitions nc + 2a and 3d + 2c where n = 2, 3, and 4. In addition the 2k + 2 and 2k + 2c electronic transitions were observed where 2k, 2k + 2 and 2k + 2c state of the doubly excited H$_2$ spectrum. In addition absolute optical cross section measurements, at 200 keV electron energy and 10 mtorr H$_2$ gas pressure determined to be within the range 10$^{-16}$ to 10$^{-21}$ cm$^2$.

**Research supported by the Atmospheric Sciences Section, National Science Foundation.


E-6 Excitation of the B$^1$Σ and C$^3$Π States of N$_2$ by Electron Impact** - S. I. Chen, R. J. Anderson and R. H. Hughes, University of Arkansas. Time resolved spectroscopy has been used to study the excitation of the B$^1$Σ and C$^3$Π states of N$_2$ by electron impact. Thirteen spectral lines of the B$^1$Σ - A$^3$Π transition were observed using 50 μsec excitation pulse width. The lines originate from the v=0 to v=2 vibrational levels of the B$^1$Σ state. Two radiative decay components with lifetimes of approximately 4 and 24 μsec were observed in each case. The long-lived cascade contributions decrease from 37% of the total radiation for the (0,0) transition to 15% for the (1,2) transition and are consistent with theoretical predictions. The λ=3371 Å spectral line of the C$^3$Π + B$^1$Σ transition was also investigated as a function of incident electron energy, gas pressure and pulse width. The C$^3$Π lifetime was determined to be 35.6 ± 3.3 nanoseconds and the pressure dependence of the observed long-lived cascade component was investigated.

**Supported in part by the NSF and the Research Corporation.
absorption by the achiral species and third-order absorption - indirect in so far as it involves the active molecule. The differential absorption as between right- and left-circularly polarized light is found for the locked-in case and for rotational averages.

065 Viscous Fluctuations and Rotated Intermolecular Forces. EDMON A. FNDIA, UNIV. OF OKLA. - The method of perturbation of the vacuum state used previously to recalculate the Casimir-Polder interaction energy has been extended to obtain the discriminating forms in the interaction energies between monomers. These energies, together with the near-zone energies, are written in terms of the optical rotatory power of the individual molecules. This involves continuation of the optical rotatory power to imaginary frequencies.


066 Theory of Stokesian of Far Charged Particles. AL J. DAVIS, OSU. - A critical look at a new theoretical approach which enhances the role of the Casimir-Fold interaction energies. For the calculation of the Casimir-Polder interaction energies in matter have been made. Firstly, a method to calculate the equilibrium coordinates, 1, in a molecule was developed that uses dynamic frequencies instead of static frequencies. Secondly, a new density correction, Δn, that depends on the material resulted from calculations of the density effect. Thirdly, a new density correction, Δn, independent of the material was discovered. Correction Δn is related to the upper limit of the liquid matter, and it varies substantially with the density of the incident particle. It is shown for aluminum that, if in addition to the shell corrections Δn, and the conventional density corrections Δn, the new corrections Δn and Δn are included, the theoretical and the experimental values are in excellent agreement. Correction Δn corresponds to an approximate increase of 1 in 10^6 at very low energies.

067 Stark Effect of Metastable H2 II. R.H. Khanna and W.C. English, Univ. of Colorado. - We have earlier reported preliminary results for Stark shift coefficients, obtained by molecular beam magnetic resonance spectroscopy for the nonpolar H2 molecule in the metastable 2P state. We have since discovered the presence of the v = 1 and v = 2, as well as the v = 0 vibrational states in our molecular beam. A correction for the earlier results for the v = 0, v = 1, and v = 2 Zeeman transitions of the v = 0, N = 2, J = 1 states for para H2 and new values for the same transitions in the v = 1 and v = 2 vibrational states are obtained in (n/kT)*2:

<table>
<thead>
<tr>
<th>Vibrational state</th>
<th>H2 = 1→2</th>
<th>H2 = 2→3</th>
</tr>
</thead>
<tbody>
<tr>
<td>v=0 H1(00)</td>
<td>0.36</td>
<td>0.60</td>
</tr>
<tr>
<td>v=1 H1(00)</td>
<td>-0.19</td>
<td>-0.31</td>
</tr>
<tr>
<td>v=2 H1(01)</td>
<td>0.12</td>
<td>0.19</td>
</tr>
</tbody>
</table>

These coefficients agree with the theoretical values within 10% or better.

*Supported in part by the Council on Research and Creative Work of the U. of Colorado.

068 Fine Structure of Hydrogen. R.J. Richardson, B.P. Gilfrich, and R.W. Hughes, Univ. of Arkansas. - The fine structure of hydrogen in the n = 3 state is investigated by the microwave-optical method of Lamb and Sanders in which the intensity of the Balmer alpha light changes as resonances are excited among the atomic substates produced by dissociative excitation of H2. Six strong resonances, na, va, qa, ca, qa, and qa of 13 are studied at frequencies between 3260 and 3900 MHz and fields between 100 and 3750 G. Results are obtained for various electron beam intensities down to 100 kA then extrapolated to zero current. To deduce the Lamb shift S and F, and fine structure AE and DE from the extrapolated results they are compared with theory which is expanded to include nonlinear electric fields according to the speed distribution measured for metastable H by Robscoe et al. The analysis and its results will be discussed.

069 Charge Exchange in H2+ - H2 and D2+ - D2 Collisions. ROBERT N. STOCKER and HERSCHEL NEUMANN, U. of Denver. - Cross sections in the center of mass energy range 25 eV to 5 keV have been calculated by a semiclassical impact parameter method, for initial ion and neutral vibrational quantum numbers v' = 0 and v = 0, respectively. The numerous vibrational states that become populated, particularly at higher energies, were represented by a basis set of 12 ion-neutral state products (SP's): the lowest-lying 6 pure SP's and 5 mixed SP's (linear combinations of pure SP's) chosen for their strong coupling to the pure SP's. Calculated high energy cross sections are ordered according to the Franck-Condon factors for the transition. Lower energy cross sections by avoided crossings in adiabatic energy surfaces. Although slight dependence on v' of the total cross section was found, all calculated total cross sections agree reasonably well with available experimental data.

070 Absolute Stopping Cross Sections of H and He+ in gases. A New Technique, H.A. Langley, Sandia Labs. - Ion backscattering has been developed recently as a microanalytical technique for depth microscopy and mass analysis. To establish an absolute depth scale, the energy loss of the ion must be known. For compound materials the additivity of the atomic stopping cross sections, Bragg's rule, is widely assumed although it has been tested by accurate measurement of cross sections for only a few cases. A new technique has been developed to measure the stopping cross sections of high energy ions (>300 keV) in gases. This technique eliminates end-effect problems by passing the ions through a long gas cell and eliminates count-rate difficulties by detecting these ions after they have scattered from a thin Au film. The technique has been applied to the gases H2, He and O2. The absolute accuracy is better than ±2%, which allows one to systematically test Bragg's rule for materials such as Al2O3, Ta2O5 and the rare earth hydrides. A previous paper has already given the details of a technique to accurately measure the stopping cross sections of reactive metals.

071 Negative Work Function for Postions in Gold. L.J. Tully, E.R. Web, and L. E. Spaner, Western Washington State College. - Measurements of the negative work function for positrons in gold will be reported. A low energy (0-100 eV) cylindrical electrostatic test or target is used and built specifically for this purpose. The spectrometer was
coherence corresponding to a few times the diffusion limit, and a sharp oscillation threshold. Energy transfer processes and operation of the xenon have been explored in argon/xenon mixtures.

This work was performed under the auspices of the United States Atomic Energy Commission.

G-3 Excimer Formation and Decay Processes in Electron Excited High Pressure Rare Gases. D. C. LONDON Stanford Research Institute. -- A theoretical model has been developed to describe excited dimer formation and decay in rare gases at pressures above 1 atm. The model is based on available knowledge of the electronic energy deposition processes, and collisional association, recombination and relaxation reactions occurring in excited rare gases. Excimer formation and decay rates in Ar and Xe are calculated as a function of atom and excitation density. The importance of excimer-deexcitation by Penning ionization is evident at high excimer densities. The results are compared with recent experimental measurements of excimer decay following pulsed excitation under conditions of both high and low excitation density. The application of the results to the development of uv lasers based on the rare gas excimer bands will be discussed.

G-4 Spontaneous and Superradiant Emission at 1750 Å in Xenon Gas at Low Temperature. Franck Cotlier and Christian Collet, Laboratoire de Marcoussis-- Spectral and time dependent studies of vacuum ultraviolet (V UV) continuum (λ = 15 Å) of electron excited gaseous xenon are presented for quasi-atmopsheric pressures (1 - 3 atm) and low temperatures: -50° C < t < 25° C. At low temperature, large increase in intensity, spectral narrowing and higher conversion efficient (of about 60%) are achieved. Population inversion is easier. Superradiant characteristic parameters are given.

SESSION HA
Electron-Molecule and Charge Transfer Collisions

HA-1 Excitation of the C 2Π State of N2 by Electron Impact. R. J. Anderson, S. T. Chen and R. N. Hughes, University of Arkansas. -- Time- resolved spectroscopy has been used to study the excitation of the C2Π state of N2 by low-energy electron impact. Measurements were carried out on the 2π 3Π A spectral line, corresponding to the (0,0) C2Π → transition, at 5890 electron beam energy and pulse widths of 0.5 and 5 usec and for gas pressures in the range 1/2 to 300 mtorr. The time-of-the C2Π (0,0) level is determined to be 39±4 nanoseconds which is in agreement with other experimental results. In the case of the 5 usec excitation pulse width the 2π 3Π A radiation was observed to contain an unresolved component (1200 µ sec) which comprises less than 1% of the total radiation and which exhibits a dependence upon the target gas pressure. Secondary excitation by collision C2Π state by collisional transfer from metastable states is being investigated as a function of the gas pressure, electron beam current, excitation pulse width, and collision chamber size.

*This work supported in part by the National Science Foundation and the Research Corporation.


Nitrogen atoms in long-lived high-Rydberg states have been produced in the dissociative excitation of N2 by electron impact. Four principal features were found in the time-of-flight distributions of dissociation fragment atoms and in the corresponding translational (kinetic) energy distributions. Appearance potentials and excitation functions were measured for the high-Rydberg states; for the slowest fragments the excitation function exhibits sharp, resonance-like structure near threshold. The core-ion model of high-Rydberg dissociation, which treats the hydrogen ion essentially as a spectator in the dissociation process, is used to interpret the data in terms of the dissociative core ion states of N2 and the appropriate dissociation limits. In addition, the high-Rydberg kinetic energy distributions are found to be in reasonable qualitative agreement with the kinetic energy distributions of N2 measured by dissociative ionization experiments.

HA-3 Dissociative Ionization of N2 by Electron Impact. J.A. Stockdale, Liliana Deleuau, and R.N. Compton, Oak Ridge National Laboratory. — An apparatus employing crossed molecular and pulsed electron beams has been used to study dissociative ionization of N2. Product ions were mass analyzed by a quadrupole mass spectrometer after drifting through a field-free region. Their energies were estimated from analysis of time-of-flight spectra. N+ and N2+ energy distributions have been obtained for electron energy from threshold to 300 eV. These will be presented with total and differential N2+ angular distributions for electron beam-detector angles from 30° to 110°.


HA-4 Vibrational Excitation of O2 by Electron Impact. D. P. Wong, M. J. W. Hoiness and G. J. Schiegl, Yale U. -- Vibrational excitation of O2 by electron impact in the energy range 4 - 15 ev has been studied with a crossed-beam double electrostatic analyzer. The scattering angle is fixed at 25° and the resolution is 60 ev. The differential vibrational cross sections for the v = 1 - 4 levels of the ground X 2Π state are found to have similar bell-shaped energy dependences, with a broad peak near 9.5 ev. The maximum differential vibrational cross section for v = 1 is approximately 4.6 x 10−18 cm2/ster and the peak cross sections to consecutive higher vibrational states diminish by a factor of about two. The differential cross sections at 25° for the excitation to the a 2Σ+ and b 2Π metastable states are in substantial agreement with the results of Trajmar et al, and show peaks near 8.0 ev and near 9.0 ev respectively. The vibrational and electronic cross sections in the range 4 - 15 ev are interpreted in terms of the resonant contributions of excited Ω states.

*Work supported by NSF and by DNA through ARO.

HA-6 Light Emission from HeI/Rare Gas Collisions. B. M. Hughes, E. C. Jones, and T. O. Tiernan, Chemistry Research Laboratory, Aerospace Research Laboratories. A new apparatus developed in our laboratories has been
Excitation of the $4\,^3S$ and $3\,^3P$ Levels of Helium by Electron Impact

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The exchange excitation of the $4\,^1S$ and $3\,^3P$ levels of helium by electron impact has been studied by means of time-resolved spectroscopy of the $4\,^1S \rightarrow 2\,^3P$ ($\lambda = 4713\text{-Å}$) and $3\,^3P \rightarrow 2\,^3S$ ($\lambda = 3889\text{-Å}$) transitions. Measurements were carried out for incident electron energies in the range 50-400 eV at helium-gas pressures of 8 and 4 mtorr. Radiative cascade transitions from the $n\,^1S$ levels and from the $n\,^3P$ and $n\,^3D$ levels contributed 12 and 10% to the total $4\,^1S$ and $3\,^3P$ populations, respectively, at 50 eV. These fractions increased to about 30 and 40%, respectively, at 400-eV electron-impact energy. The $4\,^1S$ and $3\,^3P$ direct-excitation cross sections were observed to decrease with increasing electron impact according to the relation $(\text{energy})^{-3}$. This result is in agreement with the theoretical predictions of Ochkur and Bratsev.

I. INTRODUCTION

Many experimenters have used the optical method to examine the phenomenon of electron-exchange excitation in electron-atom collisions. Particular emphasis has been given to the study of the triplet levels of the He I spectrum since they can be directly excited only through the exchange mechanism. Absolute measurements of the direct-excitation cross section and its dependence upon incident-electron energy have been obtained for several of the He I triplet levels. However, discrepancies presently exist between many of these measurements and the corresponding theoretical predictions. One example is the apparent discrepancy between theory and experiment in predicting the relative energy dependence exhibited by the direct-excitation cross-section curve (excitation function).

In the case of helium the Born-Oppenheimer theory predicts that triplet-state excitation functions will have a peak just above the threshold energy and then experience a rapid monotonic decrease with increasing energy of the incident electron. This rate of decrease of the direct cross section with electron energy $E$ is calculated to be $E^{-3}$, $E^{-2}$, and $E^{-1}$ for the $5\,^1S$, $3\,^3P$, and $3\,^3D$ levels, respectively. Calculations of the direct-excitation cross section carried out using the expansion technique of Ochkur and Bratsev predict a $E^{-3}$ dependence for all of the triplet-level cross sections. Previous experimental studies of this energy dependence have produced contradictory results. The theoretical calculations become more valid at the higher energies (above 100 eV). However, this is a difficult region to interpret experimental results because secondary excitation mechanisms, such as radiative cascade, generally make significant contributions to the low-level optical measurements. The $4\,^1S$, $3\,^3P$, and $3\,^3D$ apparent-cross-section energy dependence determined by Kay and Showalter indicates a single $E^{-3}$ dependence for the $4\,^1S$ cross section for the higher energies. However, they found that the $3\,^3P$ and $3\,^3D$ levels have excitation functions which exhibit a far more complicated energy dependence at these higher energies. A log-log plot of their apparent cross section versus incident-electron energy shows that the $3\,^3P$- and $3\,^3D$-level excitations each exhibit a $E^{-1}$ dependence for energies above approximately 100 eV. Subtracting this energy dependence from the original data points leaves a second component that varies as $E^{-3.4}$ and $E^{-3.7}$ for the $3\,^3P$ and $3\,^3D$, respectively. The slow components are attributed by the authors of Ref. 4 to the effects of secondary excitation on the levels in question.

The present work uses time-resolved spectroscopy to determine the energy dependence of the direct-excitation cross section. The effects of secondary excitation mechanisms which have temporal decay rates different from the radiative rate of the upper level of the transition under study are subtracted off from the total light intensity. This technique provides direct information about the excited-atom density produced by direct electron-impact excitation. The time-resolved technique is a simple and useful method to isolate, identify, and quantitatively measure the effects of secondary excitation mechanisms and therefore can be used effectively in conjunction with absolute-intensity measurements to determine direct-excitation cross sections.

II. EXPERIMENT

The time-resolving apparatus shown in Fig. 1 was similar to that used in our previous experiments. Helium gas passed through a cooled trap and into the excitation chamber through a small orifice. The rate of helium-gas flow was held...
Excitation of the 3p Level of Helium by Electron Impact. R.J. Anderson, R.M. Hughes and J.H. Tong, University of Arkansas. The excited state of the 3p level of helium by electron impact has been studied by means of a high-sensitivity interferometer of the 3p-2s transition. The study was carried out for electron energies within the range 40-400 eV, at a helium gas pressure of 4 Torr. Under these conditions the total 3p-2s transition intensity of the 3889 Å line was observed to vary linearly with both electron beam current and target gas pressure. Radiative cascade transitions from upper 3p and 2s states were observed to contribute about 10% of the total 3889 Å light output at 40 eV. This fraction increased to about 50% at 400-eV electron impact energy. Within experimental error, the energy dependence of the 3p-2s direct excitation cross section was observed to decrease with increasing energy according to the relation \( (E)^{-3} \). This result is in agreement with the theoretical calculations of Ochkur and Bratsev which predict a similar dependence above 50 eV.

Work supported by the National Science Foundation.


Measurements of Electron Impact Cross Sections of the Individual Magnetic Sublevels of the 3p and 4p States of Potassium. J. E. Sloten, S.W. Bell and H.M. Loomis, University of Wisconsin. By means of a high-resolution interferometer, a scanning Fabry-Perot interferometer spectrograph, and a spectrometer, the six K I 3p configurations of the 4p terms have been resolved under a magnetic field of 1.8 KG. At incident energies of 10.5, 16.8, and 23 eV, the relative intensities of the \( 3p_1=3/2 \) and \( 1/2 \) components are respectively 0.94, 0.79, and 0.70 which gives the ratio of the cross section of the \( 3p_1=1/2 \) to that of \( 3p_1=3/2 \) as (in the limiting uncoupled states) 0.645, 0.685, and 0.55. The corresponding theoretical values of this ratio based on the three-state close-coupling calculation are 1.050, 0.825, and 0.725.

Work supported by the U.S. Air Force Office of Scientific Research and by the Air Force Cambridge Research Laboratories, Office of Aerospace Research.

Excitation of Band Emissions in Nitrogen by Secondary and Primary Electrons. W.L. Bost and W.A. McDonnell, III, Southern Illinois University at Carbondale. Secondary electrons were produced in H2 by fast primary electrons (>1 keV). Resulting band emissions excited in the gas by secondary and primary electrons were monitored for pressures from 10^{-8} to 1 Torr. Secondary and primary electron contributions to the total excitation of a band were separated using a movable optical detector that scanned luminosity profiles in the reaction region. Second positive (2P6) bands of H2 were excited solely by secondary electrons whereas first negative (1P6) bands were excited by primary and/or secondary electrons depending on the interaction volume viewed. The observed intensities depended sensitively on the energy spectrum of the secondary electrons. This fact was used to infer the energy spectrum of the secondary electrons. The intensity ratio \( B_2P(0,0) \)/\( B_2P(1,0) \) as excited solely by slow secondary electrons was found to be about 0.5 over a large range of pressures, primary electron energy, and detector position. The present results were compared with atmospheric measurements of auroral emissions and electron spectra.

Scattering of Alkali Halides by Low Energy Electrons. M.G. Pickles, R.C. Slater, and R.C. Stern, Columbia University. -- Laboratory differential cross sections for the scattering of thermal beams of CsCl, KI, and TIP by 0.5 to 15 eV electrons have been measured using the molecular beam recoil technique. A novel kinematical analysis used to transform the scattered electrons from the laboratory to the scattering plane to the Born theory.

Supported by the National Science Foundation.

Mass Spectroscopic Analysis of Helium-4, Helium-3, and Carbon-13. J.R. Chabon. -- The time dependence of the decay of mass 3 he, 3 He, and C13 in the mass spectrometer is determined by means of a time-of-flight apparatus. Scans in helium-hydrogen mixtures using the decay of mass 3 He produced in the microwave cavity indicate that helium density dependent collisional processes such as the reactions of these rare gases with helium are not important.

Supported by the National Science Foundation.
Excitation of H Atoms to the 4s State by 10- to 35-keV Ground-State H-Atom Impact on H_2 and N_2*

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In this note we report the measurement of the absolute cross sections for the collisional reaction H(1s) + T → H(4s) + T* where T represents ground-state H_2 or N_2 targets and T* represents these targets in final states which include excited states as well as ground states. The kinetic energy range of the H-atom projectiles was from 10 to 35 keV.

The technique and apparatus was similar to that used by Hughes et al. for the measurement of excitation to the n = 3 level of H by H(1s) impact on gases. A magnetically selected proton beam passed through a differentially pumped neutralizing chamber into an evacuated chamber where a strong transverse electric field swept the remaining protons from the beam. The neutrino beam component then passed through a differentially pumped collision chamber containing the target gas where the excitation took place. The beam then entered an evacuated observation chamber where the excited fast atoms decayed in flight. An increase over the background count rate would be expected when the quadrupole mass filter was tuned to pass a product ion if this ion was produced from the primary ion beam. Due to statistical variation in the count rate of the primary beam, appearance of product ions was a much more sensitive mode of observing a reaction in the primary ion beam.

There was no indication of photodissociation of the hydrated oxonium ions (H_2O)_n^+ for n = 1-3. Only an upper limit to the cross section could be inferred. Since no definite signal was found, the standard deviation of the background signal was evaluated and used as the reported upper limit on the cross section. This cross section was found for each parent ion for narrow band radiation at 5800, 5900, 6000, 6100 Å and for broad band radiation. These results for both broad band and narrow band conditions are summarized in Table I. Variation in the upper limits placed on the cross section reflect limits produced by experimental conditions rather than any indication of probable value of the true cross section.

The upper limits on the cross sections given above are not sufficient to be used alone to predict the importance of photodissociation in the atmosphere on these ions since only a few percent of the energy of the solar spectrum available for these processes lies in the wavelength range investigated and it is at least conceivable that the photodissociation cross sections have structure such that large cross sections occur in the solar wavelength range which were not detected in the limited spectral range studied here. This possibility is actually unlikely, since the weak bond energies characteristic of the cluster ions is largely electrostatic in character. The electronic transition energies in the clusters are probably only slightly perturbed from the values in the separated fragments and therefore correspond to energies well above the photon energy of the experiment (or well above the energy of the bulk of the solar photon flux). Thus it is unlikely that the true photodissociation cross sections are as large as the upper limits established here for wavelengths anywhere in the visible or longer wavelength spectral region.

Charge-Changing Collisions by 20- to 120-keV H(2s)-Atom Impact on N₂, Ar, and He\(^+\)

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Absolute cross sections have been measured for the reaction \(H(2s) + T - H^+ + T + e\), where \(T\) represents \(N_2\), \(Ar\), and \(He\). The measurements were carried out for impact energies in the 20-120-keV range. The experimental results for impact on \(He\) and \(N_2\) are in general agreement with calculations based on the method of Bates and Walker. The calculation for impact on \(Ar\) overestimates the experimental stripping at the lowest energies but approaches satisfactory agreement at the highest energies. A few cross sections are presented for electron capture into the stable \(H^+\) state for \(H(2s)\) impact on these gases. The capture cross sections are small and are about 7\% of the total capture cross sections by protons having the same energy.

I. INTRODUCTION

Bates and Walker\(^1\) have formulated a description of the collision reaction \(H^* + T - H^+ + T + e\), where \(H^*\) is an excited hydrogen atom. Their basic assumption is that the field of the proton is important only in that it determines the orbital contribution to the electron velocity relative to the target atom and determines the binding energy of the electron. The energy required to free the electron from the projectile atom is supplied by the collision between the electron and the target atom. The problem is basically reduced to an electron-atom collision process. In the Bates-Walker formula and the experimental cross section for scattering of electrons\(^2\) from the target gas is folded into the stripping calculation. Gilbody et al.\(^3\) have measured stripping cross sections for \(H(2s)\) impact on \(H_2\), \(N_2\), \(Ne\), \(He\), \(Ar\), and \(Kr\) in the 10-30-keV range and found that the Bates-Walker calculation badly overestimates the stripping for impact on \(Ar\) and \(Kr\).

Hughes and Kisner\(^4\) have pointed out that if the screening of the proton can be neglected in the scattering of the orbital electron from the target atom, as suggested by Bates and Walker, then the screening of the proton by the electron can also be neglected. In this approximation, electron capture also becomes an important process in quenching excited states in the projectile atom. Hughes and Kisner measured the collisional destruction of the 3s state in the fast hydrogen projectile and found they could fit their data to a model which incorporates both stripping and electron capture. However, Gilbody et al.\(^5\) dismiss electron capture as an important process in the collisional destruction of 10-30-keV \(H(2s)\) on the basis of small cross sections for the production of \(H^+\) by \(H(2s)\) impact. Thus some interesting questions have arisen regarding charge-changing collisions involving excited hydrogen atoms.

II. APPARATUS

Figure 1 is a schematic diagram of the apparatus. A mass-analyzed beam of protons entered a differentially pumped neutralizing chamber filled with the same species as the target gas in the collision chamber \(C\). The partially neutralized beam passed through the exit aperture of the neutralizing chamber into an evacuated region where a transverse electric field \(R\) swept the remaining protons from the beam. The length of the path through the electric field was dictated by the requirements that the protons be deflected from the beam axis and that only a minimal number of \(H(2s)\) be quenched in the process. This last requirement is equivalent to the statement \(\nu > d\) where \(\nu\) is the velocity, \(\tau\) is the lifetime of the 2s state in the electric field,\(^6\) and \(d\) is the path length through the field. The path length of 54 cm satisfied these requirements in our energy range. After leaving the field, the beam was primarily composed of \(H(1s)\) and \(H(2s)\) atoms.

The beam next passed through a Stark quenching assembly \(A\). This electrode assembly consisted of five plates, spaced 1 cm apart, each with an
Destruction of the 3s State in Atomic Hydrogen by Fast-Atom Impact on \( \text{N}_2, \text{Ar}, \text{and} \, \text{H}_2 \)

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Cross sections have been determined for the destruction of the 3s state in atomic hydrogen by 10-, 25-, and 35-keV hydrogen-atom impact on \( \text{N}_2, \text{Ar}, \) and \( \text{H}_2 \). The experimental values support the concept of two destruction mechanisms. One mechanism involves the collisional ionization of the excited atom, which has been treated quantitatively by Bates and Walker. The other mechanism involves electron capture by the fast-atom nucleus.

INTRODUCTION

Bates and Walker\(^1\) have treated the collisional ionization of fast excited hydrogen atoms passing through a neutral gas. One of the basic assumptions of their theory is that the field of the nucleus of the fast atom is important only in that it determines the binding energy of the electron. They assumed that the energy required to set the electron free would be provided in the elastic collision between the electron and the target atom. Thus by neglecting the field of the nucleus, the problem is reduced to an electron-atom collision.

They developed a formula in which the experimentally determined total electron scattering cross sections\(^2\) are used. They computed electron-loss cross sections for impact on \( \text{N}_2 \). At the \( n = 3 \) level and for energies beyond 10 keV, the computed electron-loss cross section versus atom velocity curve lies close to the total electron cross section versus electron velocity curve. (The electron velocity approximates the fast-atom velocity in our energy range beyond 10 keV since the translational velocity of the center of mass is larger than the mean orbital velocity of the electrons.) This was the only quenching mechanism they considered.

APPARATUS AND PROCEDURE

Protons were passed through a differentially pumped 8-cm-long collision chamber. The partially neutralized beam passed through the exit aperture into an evacuated observation region. The beam was highly collimated so that no protons intercepted the edge of the \( 4\text{-in.} \) diameter exit aperture. An EMI 9558B photomultiplier fitted with an \( H_2 \) interference filter detected the 3s-2p radiation at a distance of \( \nu \tau \) from the exit aperture, where \( \nu \) is the atom velocity and \( \tau \) is the lifetime of the 3s state (160 nsec). At this point we were assured that the shorter-lived 3\( d \) and 3p states had decayed to a negligible fraction of the light.

An expression has been developed which describes the buildup of fast excited atoms in such a collision chamber.\(^3\) It can easily be modified to the form used in this experiment:

\[
\frac{I}{n_0} = K \left( \frac{\sigma_1/Q_s + Q_s/Q}{L/\nu + \alpha} \right) \left( 1 - \frac{e^{-L/\nu}}{e^{-L/\nu} - \beta + \gamma} \right),
\]

where \( I \) is the intensity of the 3s-2p radiation emanating from the beam; \( n_0 \) is the proton density in the beam at the entrance aperture of the collision chamber; \( \rho \) is the target gas density in the collision chamber; \( K \) is a constant at a given energy; \( L \) is the collision chamber length; \( \sigma_1 \) is the total stripping cross section; \( Q_s \) is the cross section for excitation of ground-state hydrogen atom to the 3s state by atom impact on the target gas; \( Q \) is the cross section for capture into the 3s state of hydrogen by proton impact; \( \alpha = \rho L Q_s \) where \( Q_s \) is the cross section for collisional destruction of the 3s state; \( \beta = \rho L \sigma_1 \); and \( \gamma = \rho L a_0 \).

The intensity of the 3s-2p light was measured as a function of the target gas pressure in the collision chamber. The proton density \( n_0 \) was determined by using a secondary electron detector. The secondary electron detector measured the total particle density in the beam since neutrals, produced by charge transfer in the collision chamber, and protons have nearly the same detection efficiency.\(^4\) The gas density \( \rho \) was measured with a calibrated ion gauge. The quantities \( \sigma_1 \) and \( \sigma_2 \) were taken from Allison.\(^5\) The cross section \( Q \) was obtained from Hughes et al.\(^6\) and the cross section \( Q_s \) was taken from Hughes et al.\(^7\).

Figure 1 shows a computer fit of Eq. (1) to data for impact on \( \text{Ar} \) using \( Q_s \) as the fitting parameter. In principle, two points on the \( I/n_0^2 \) versus \( \rho \) curve is sufficient to make one determination of \( Q_s \).

Table I displays our values for the destruction cross section \( Q \) along with values for the collision-
Excitation of H Atoms to the n = 3 States by the Impact of 10 to 35-keV Ground-State H Atoms on He, Ne, Ar, H₂, O₂, and N₂

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Absolute cross sections have been measured for the excitation of hydrogen atoms to the 3s, 3p, and 3d states by the impact of ground-state hydrogen atoms on He, Ne, Ar, H₂, O₂, and N₂ in the energy range from 10 to 35 keV. In this energy range the cross sections for the different angular momentum states are generally the same order of magnitude (10⁻¹⁴ cm²). Excitation to the s state is more competitive with the p-state excitation at the n = 3 level than at the n = 2 level. Excitation to the 3d state is not as likely as excitation to the 3s or 3p states. Cross sections for the production of Balmer α radiation have been computed. Polarization fractions for the 3d → 2p radiation have also been measured.

INTRODUCTION

There have been several measurements of the collisional excitation of fast ground-state hydrogen atoms by impact on gases. Excitation to the n = 2 states has been studied for impact on the rare gases, i.e., He, Ne, Ar, H₂, O₂, and N₂. Excitation to the 3s states has been measured for impact on N₂. Excitation to the n = 2 and n = 3 level has been treated theoretically for impact on H by Bates and Griffin. Levy has recently treated excitation to the n = 2 states for impact on the rare gases. This investigation reports measurements on the excitation to the 3s, 3p, and 3d states in the energy range from 10 to 35 keV for impact on He, Ne, Ar, H₂, O₂, and N₂.

APPARATUS AND ANALYSIS

The apparatus is similar to that used in the study of excitation to the 3s state by impact on N₂. The collimation of the beam was increased for this experiment so that the beam emerges from the 1/16-in. diam exit aperture of the collision chamber with only minimum interaction with the aperture edges.

The neutral beam density was measured by secondary electron emission from a nickel target. Calibration was accomplished by comparing with a proton beam at the same energy. The efficiency for secondary emission for neutral impact was taken to be 1.09 times that of protons in this energy range. Two collision chamber lengths were used to check the excited atom buildup, 5 and 8 cm. The final data were obtained using the shorter chamber. The 9558B EMI photomultiplier recorded the intensity of the Balmer α emission as a function of x (cm). The 100, 5, 2, and 160 nsec (3s) data were obtained, 5.6 nsec (3p), and 5.4 nsec (3p) data were subtracted from the remainder.

FIG. 1. Decay of Hα light from hydrogen atoms emerging from a collision chamber filled with Ne as a target gas (chamber length 5 cm). The distance 6 is measured from the exit aperture. The 3d decay is obtained by subtracting the long-lived 3s decay from the total decay curve circles, and the 3p decay is obtained by subtracting the longer-lived 3d from the remainder.
is 0.824 at \( R_0 = 3.5 \), whereas in the work of Peek et al.,\textsuperscript{3} it is -1.1, located at \( R_0 = 4.1 \).\textsuperscript{6}

The total charge-transfer cross section \( \sigma \) is now calculated by Eq. (1) with the help of Eqs. (9) and (10) from \( R_0 = 2.8 \), since the cross section is found to be insensitive to the chosen form of the \( X(R) \) curve below this value of \( R_0 \). In Fig. 3, \( \sigma \) for \( \text{Li}^+ - \text{Li} \) charge transfer is plotted as a function of inverse velocity, \( 1/v \), along with the experimental curve.\textsuperscript{7} The theoretical curve of Ref. 5 is also given in the figure for the purpose of comparison. The curve of the present work is composed of a smoothly varying and an oscillatory part. The smoothly varying part of \( \sigma \) increases with \( 1/v \) and the oscillatory part has a constant frequency but its amplitude decreases with \( 1/v \).

The curve of the present work is in reasonable agreement with the experimental results of Ref. 6. As is expected from the discussions in the previous paragraph, the present theoretical curve is in good agreement with the theoretical work of Ref. 5. Since the maximum value of \( \Delta E(R) \) in our calculations comes out to be less than that used in Ref. 5, the frequency of oscillation is less than that obtained by them, as is expected from the theory.\textsuperscript{3}

This method of atomic-wave-function expansion may be useful where the \( \Delta E(R) \) curve for the reacting particles is not known. However, further analysis of the problem is dependent upon the accuracy of the wave function, choice of the form of \( \mathcal{H}^\prime \), and other approximations used in the theory.

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\textsuperscript{4} E. Clementi, Table of Atomic Functions (IBM, San Jose, Calif., 1965).

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Excitation to the 2s State of Hydrogen by 20- to 120-keV Hydrogen-Atom Impact on He, Ne, Ar, and \( \text{N}_2 \)^\textsuperscript{†}

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Absolute cross sections have been measured for the production of hydrogen atoms in the metastable 2s state by fast (20- to 120-keV) ground-state hydrogen-atom impact on He, Ne, Ar, and \( \text{N}_2 \). The shape of the excitation curve for impact on He is not reproduced by the Born-wave calculation of Levy although the theory curve intersects the experimental curve near the two energy extremes. The scaled Born curves of Levy lie below the experimental curves for impact on Ne and Ar, although there is a general agreement near 20 keV for both gases. Experimental values for the cross sections for production of the 2s and the 2p states by hydrogen-atom impact on the four gases are presented in the range of 1-120 keV by combining and weighting the data of Birely and McNeal with the present data where they overlap.

INTRODUCTION

There have been two previous measurements of the excitation to the 2s state of hydrogen by fast ground-state hydrogen-atom impact on the rare gases.\textsuperscript{1,2} Birely and McNeal\textsuperscript{3} have also made such measurements for hydrogen-atom impact on \( \text{N}_2 \) and \( \text{O}_2 \). The energy range of Birely and McNeal\textsuperscript{3} was about 1-25 keV, while Orbell et al.\textsuperscript{4} investigated the range from 5 to 40 keV. This investigation ex-
Electron-capture and -loss cross sections have been measured for fluorine ions in nitrogen gas in the energy range from 5 to 54 MeV. The velocity dependence of all the capture cross sections is described by a power law with the power ranging from -4 to -8, being larger for lower incident charge states and for more than one electron captured in a single collision. Good agreement with the theoretical predictions of Nikolaev has been obtained for the capture cross sections by the fully stripped fluorine nucleus. The ratio of double- to single-electron-capture cross section has been discussed in terms of a geometry-independent component of the capture process. Broad maxima have been observed in this ratio for the higher incident charge states. Maxima are observed in the velocity dependence of the single- and multiple-loss cross sections and these are consistent with the predictions of the model of Bohr and Lindhard.

CONCLUSIONS

Electron-capture and -loss cross sections have been measured for fluorine ions in nitrogen gas in the energy range from 5 to 54 MeV. The velocity dependence of all the capture cross sections is described by a power law with the power ranging from -4 to -8, being larger for lower incident charge states and for more than one electron captured in a single collision. Good agreement with the theoretical predictions of Nikolaev has been obtained for the capture cross sections by the fully stripped fluorine nucleus. The ratio of double- to single-electron-capture cross section has been discussed in terms of a geometry-independent component of the capture process. Broad maxima have been observed in this ratio for the higher incident charge states. Maxima are observed in the velocity dependence of the single- and multiple-loss cross sections and these are consistent with the predictions of the model of Bohr and Lindhard.

Excitation of the $n=4$ Level of He$^+$ by Electron Impact on He$^+$

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The simultaneous ionization and excitation of helium to the $n=4$ level of He$^+$ by 200-eV electron impact on helium has been studied by time-resolved spectroscopy of the $\lambda=4686$-Å (4+4+3) line of He$^+$. The study revealed that the excitation process is complex. It appears that only about 70% of the excitation of the $\lambda=4686$-Å line can be accounted for by direct simultaneous ionization and excitation of the helium atom to the $n=4$ level of He$^+$ under single-electron-atom collision conditions.

INTRODUCTION

Absolute cross sections for the production of the 4+4+3 line of He$^+$ by the simultaneous ionization and excitation of He under electron impact has been determined by two different groups with results that are in very close agreement. However, these experiments simply measured the total light output and did not resolve the fine-structure components in the line. Some means of resolution must be used in order to determine the cross section for exciting the individual fine-structure levels.

There are at least two ways that this line complex, which consists of the $4s-3p$, $4p-3s$, $4p-3d$, $4d-3p$, and $4f-3d$ transitions, might be resolved. The frequencies of many of these components are sufficiently different that high-resolution interfer-
exchange takes place, it is of much shorter range.

IV. DISCUSSION

The results obtained in this paper for the charge-exchange reaction

\[ \text{H}^+ \text{Be}^+ \rightarrow \text{H}^+ \text{Be}^+ \]

are of interest from several points of view. First, the methods which we have employed yield cross sections at low energies for which conventional linear-trajectory methods are not at all applicable. In this connection it is worth noting that our technique may be extended in a straightforward manner to more complex systems. The proton-hydrogen-atom exchange reaction previously studied represented a "six-state" calculation and an application to atom-molecular collisions is currently under way.

From the point of view of understanding a reaction process our method is particularly suitable. The phenomenon of multiple electron exchange characterizing charge-exchange reactions is a simple analogue of the type of process commonly conceived for more complex reactions. For example, it is thought that a "transition state" may execute several vibrations before energy is distributed in such a way as to facilitate the conversion from reactants to products. It is hoped that the present methods may be applied to such processes in the near future.

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Production of Lyman-Alpha Radiation by 20- to 120-keV Hydrogen-Atom Impact on He, Ne, Ar, and N$_2$$^\dagger$

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Absolute cross sections have been determined for the production of Lyman-α radiation by 20–120-keV ground-state hydrogen atoms impacting on He, Ne, Ar, and N$_2$. Atom impact on He follows the predicted energy dependence of Levy’s Born wave calculation of 2p excitation beyond 30 keV. Although the experimental value remains about 25% higher than the theoretical value in this region, the agreement is well within experimental error. For Ne, Levy’s scaled Born calculation for 2p excitation agrees reasonably well with experiment. However, it is particularly apparent for impact on Ar that the scaled Born calculation underestimates the excitation at the higher energies. All cross sections decrease more rapidly with energy initially than at the higher energies, where a characteristic flattening of the cross-section-vs-energy curve occurs, suggesting the importance of simultaneous excitation of the target and projectile atoms at these energies.

I. INTRODUCTION

Production of Lyman-α radiation by hydrogen atom impact on N$_2$ has been measured by Dahlberg et al. for 20–130-keV impact, and by Birely and McNeal below 30 keV. Similar measurements have been carried out on He, Ne, and Ar by Birely and McNeal to 25 keV, by Dose et al. to 55 keV, and by Orbell et al. to 40 keV. We extend the energy range in this investigation of these rare gases.

Levy has calculated the excitation of these rare gases using the Born wave method by describing the target atoms by elastic and inelastic x-ray form factors. In the case of helium, he found excellent agreement with the experimental work of Orbell et al. when the experimental values for 2s and 2p cross sections were summed over the entire experimental range of 5–40 keV. Some discrepancies became apparent when the two cross sections were treated separately. Levy also found that he could reasonably reproduce the n = 2 measurement of Ref. 5 for Ne, Ar, and Kr by scaling his Born calculation by a velocity-dependent factor obtained by a comparison of the theoretical ionization cross sections with the experimental values. Birely and McNeal made n = 2 measurements for impact on the rare gases and discovered an apparent discrepancy in the helium work of Ref. 5. Both experiments used the same optical calibration, which is based on the charge-transfer work of...

SPECTROSCOPY WITH GAS TARGETS

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The spectroscopy of fast-ion impact with gas targets can be divided into two obvious categories: (1) the study of emissions from the target atoms or molecules, and (2) the study of emissions from the fast atoms resulting from electron capture or dissociation of the incident ion. Since the emphasis of this conference would seem to be on the spectroscopic study of fast atom emissions, I will restrict the topic to the second category, namely, fast atom emission.

Consider, for example, the process of simple electron capture by the incident ion into an excited state of the resulting fast atom. The reaction is: \( H^+ + T \rightarrow H^* + T^+ \), where \( H^+ \) represents the incident ion, \( H^* \) represents the resulting excited fast atom, and \( T \) represents the target.

In order to study such reactions, an ion beam is passed through a differentially-pumped collision chamber containing the target gas (see Fig. 1). The production of fast excited atoms inside the chamber is given by

\[
\frac{dn^*}{dx} = -\frac{n^*}{VT} + QF/V
\]  

(1)

where \( n^* \) is the excited atom density, \( x \) is the distance measured from the

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Electron Capture into the $n=2$ States of Hydrogen by Fast Proton Impact on Gases

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Cross sections for electron capture into the 2s and 3p states of atomic hydrogen have been measured for proton impact on He, Ne, Ar, N$_2$, and O$_2$. In addition, capture into the 2s state has been measured for proton impact on H$_2$. Generally, these measurements have been carried out in the energy range from 20 to 130 keV. Absolute calibration of the helium-filled iodine Lyman-alpha counter was obtained by a normalization procedure involving previous 2p capture measurements for impact on He, Ne, and Ar, after an investigation of the detector response for electron impact on H$_2$. Calibration for the 2s capture was established by determining the 2s cross section relative to the 2p cross section for 20- and 30-keV impact on Ne. The polarization effect in the Stark-quenched 2s radiation was minimized by observing the Stark-induced radiation at 34.7° to the electric field direction. The 2s cross sections relative to the previously measured 3s cross section show a remarkable (about 10%) agreement with the $n^{-3}$ law (predicted at high energies) above 20 keV for all gases, excluding He. It appears that the $n^{-3}$ behavior sets in at about 100 keV for He. In general the 2s cross section tends to be somewhat higher than predicted by the $n^{-3}$ law for impact on He in the range from 25 to 100 keV. It appears that the 2s cross sections will agree with the coupled-state calculation of Sin Fai Lam for impact on He above 100 keV. The 2p cross sections are lower than those predicted by theory for impact on He in this energy range. The 2p cross sections relative to the previously measured 3p cross sections appear to roughly follow an $n^{-3}$ behavior at the higher energies, again with the possible exception of helium. Comparisons are made with the results of other experimental investigations.

I. INTRODUCTION

Electron capture into the $n=2$ states of hydrogen by fast proton impact on gases has been the subject of several experimental investigations within this energy range. This investigation generally extends the energy range of the incident protons.

Pretzer et al. and Jaecks et al. calibrated their detector by normalizing its response to the cross-section determination of Fite and Brackmann for the reaction $e^- + H_2 \rightarrow \text{L}_n$. Fite's calibration in turn was obtained by normalizing to the Born approximation for the reaction $e^- + H \rightarrow \text{L}_n$. The calibration of Bayfield was based on the photoelectric efficiency of the tungsten surface of his detector. The calibration of Andreev et al. was based on the calculated sensitivity of an ionization chamber filled with NO. (All others calibrated either by normalizing to one of these works or by normalizing to the Born approximation for either protons on helium or atomic hydrogen. However, Gally has indicated that the Born approximation fails to describe the charge-capture process into excited states.) There is some uncertainty in the absolute calibration of these investigations because polarization of radiation was not taken into account. In particular, the 2s cross-section measurements have been performed by monitoring Lyman-alpha emission from Stark-quenched 2s atoms, assuming the radiation to be isotropic. This radiation, however, can be strongly polarized, as first observed by Fite et al., Sellin et al., and Andreev. Such large polarization fractions can appreciably affect the apparent cross section. Further, the polarization fraction can be dependent on the experimental apparatus.

Polarization corrections to the data of Bayfield, Jaecks, and Andreev are difficult to assess, each for a different reason. Jaecks and Andreev observed the induced 2s radiation from 2s atoms born in the quenching field. Crandall has calculated the polarization of this radiation in the sudden approximation which applies to the work of Jaecks and Andreev. At 600 V/cm the polarization is about -18%. Jaecks used a quench configuration where the electric field was perpendicular to the beam direction but reversed directions as the beam passed through the field. The direction of the field was generally either parallel or antiparallel to the viewing direction. These field uncertainties contribute to the difficulty in applying a correction factor to this work. Andreev viewed the quench radiation perpendicular to a constant electric field of 600 V/cm which also was perpendicular to the beam direction. However, he used a monochromator with reflecting optics which treat the polarization components differently. Further, both Jaecks and Andreev obtained their 2s cross section by subtracting the 2p radiation obtained with the field-off mode from field-on mode. The polarization calcula-
Electron Capture into the \( n = 3 \) States of H by Fast \( H^+ \) Impact on Gases*

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Absolute cross sections for electron capture into the \( 3p \) and \( 3d \) states of hydrogen have been measured for 10- to 100-keV proton impact on He, Ne, Ar, H\(_2\), N\(_2\), and O\(_2\). Improved \( 3s \) cross sections are presented for these gases from 10 to 120 keV. An apparent maximum in the \( 3p \) cross section occurs in this energy range for all gases. The \( 3d \) cross sections decrease monotonically with increasing impact energy according to an \( \exp[-(E/K)^{1/2}] \) relationship, where \( E \) is the impact energy and \( K \) is a constant, with the exception of helium which shows a maximum in the \( 3d \) cross section between 15 and 20 keV. The value of \( K \) is identical for all the diatomic gases. Balmer-\( \alpha \) cross sections are synthesized from these results. Polarization of the \( 3d-2p \) radiation is reported.

INTRODUCTION

Cross sections for electron capture into the \( 3s \) state\(^1\) and \( 4s \) state\(^2\) of atomic hydrogen have been previously measured for \( H^+ \) impact on He, Ne, Ar, H\(_2\), N\(_2\), and O\(_2\) in the energy range from about 5 to 120 keV. In this paper we report cross sections for capture into the \( 3p \) and \( 3d \) states in the range from 10 to 100 keV along with improved \( 3s \) cross sections by \( H^+ \) impact on these same gases from 10 to 120 keV.

Cross sections for capture into the \( n = 3 \) states by \( H^+ \) impact on N\(_2\) in the range of 10 to 35 keV have previously been published.\(^3\) The technique involves passing a highly collimated beam of monoenergetic protons through a differentially pumped collision chamber of known length and containing the target gas at a known pressure. Electron capture takes place in the collision chamber. The partially neutralized beam emerges into an evacuated observation region with only a minimum of interaction with the exit aperture of the collision chamber where the decay of Balmer-\( \alpha \) (\( n = 3 - 2 \)) radiation is measured as a function of the distance from the exit aperture of the collision chamber. When a small background produced by the interaction of the beam with the residual gas in the observation chamber is subtracted, the Balmer-\( \alpha \) light is found to be a three-mode decay showing the theoretical \( 3s \), \( 3p \), and \( 3d \) radiative lifetimes. Radiation from these levels can thus be separated and identified by their corresponding lifetimes, which allows the capture cross sections to be determined for each individual level.

APPARATUS

Data were taken from 10 to 35 keV using the apparatus described in Ref. 3. Data from 30 to 120 keV were taken with a larger accelerator. These two machines were used in producing the \( 3s \) data for Ref. 1. Since then, the detection system has been greatly improved, principally by cooling the photomultiplier. The beam collimation has also been improved.

Both accelerator systems provided high beam collimation with no evidence of proton interaction with the exit aperture of the collision chamber. The small accelerator system was provided with lock-in detection\(^7\) and the higher-energy system was provided with dc amplification of the photomultiplier signal.

Collision chambers about 3 and 6 cm in length were used in the measurements. The bulk of the data was taken with the shorter chamber after it was established that the buildup of excited atoms in the two chamber lengths was consistent with theory.

The sensitivity of the photocathode surface was mapped out for the EMI 9558 B photomultiplier tube used on the larger accelerator, and a 1 cm length of the photocathode of known spatial sensitivity was selected. A \( \frac{1}{2} \)-cm-long mask was used on the small-machine photocathode. Different orientations of this tube, an EMI 6095 B, and interchanging with an EMI 9558 B tube failed to change the decay curve.

The possibility of Doppler broadening affecting the data at the higher energies was checked; however, the experimentally determined band pass of the Baird-Atomic B-1 filters is sufficiently broad to accept the \( f/4 \) cone of light used without appreciable attenuation. (A Doppler broadening correction is applied to the data at 100 keV which is smaller than the reproductibility of the data and is about 4\% at 120 keV.)

Stark mixing of certain levels is of some con-
Production of $n=3$ and $n=4$ States of Atomic Hydrogen by Electron Impact on $H_*$

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Absolute cross sections for the production of $H_*$ ($n=3\rightarrow2$) and $H_8$ ($n=4\rightarrow2$) emissions by electron impact on $H_2$ have been measured in the energy ranges 20–400 eV and 30–400 eV, respectively. Time-resolved spectra were taken for 50, 75, and 110-eV impact in which the $s$-state decays could be definitely identified since the decay times agreed with theory. All decays could be fit with a two-mode decay scheme, the second mode having a lifetime somewhat longer than the $s$-state theoretical lifetime. The possibility of Stark mixing of certain states is discussed. Cross sections for the production of atoms in the $3s$ and $4s$ states are estimated for 50, 75, and 110 eV. The $3s\rightarrow2p$ contribution to $H_*$ and the $4s\rightarrow2p$ contribution to $H_8$ are about 25% and 14%, respectively, at these energies.

INTRODUCTION

Vroom and de Heer1 have measured the absolute cross sections for the production of the $H_*$ and $H_8$ emissions by the impact of fast electrons on $H_2$. We report similar cross-section measurements within a more restricted energy range which are in agreement with their results within experimental error. Our cross sections are about 25% lower. In addition, we have attempted to analyze the decay modes in these radiations by time-resolved spectroscopy.

The production of $H_*$ ($n=3\rightarrow2$) and $H_8$ ($n=4\rightarrow2$) emissions by electron impact on $H_2$ can result from the possible dissociative reactions

\begin{align*}
e+H_2 & \rightarrow e+H+H^*, \\
e+H_2 & \rightarrow e+2H^++H^*, \\
e+H_2 & \rightarrow H^++H^*,
\end{align*}

where $H^*$ represents the appropriate initial excited states that decay with the emission of the $H_*$ and $H_8$ radiations.

Absolute cross sections for populating these excited states would be of interest. This is not a particularly easy problem, however. The energy spacing between atomic fine-structure levels are very small and are subject to Stark mixing according to the environmental conditions in which the emitting atom finds itself in the collision chamber. Thus, it may be that the emission cross sections for $H_*$ and $H_8$ may be dependent on the conditions under which the experiment is performed.

Under time-resolved spectroscopy, $H_*$ radiation should exhibit primarily $3s$, $3p$, $3d$, and $4f$ decays which have field-free lifetimes of 160, 54, 15.6, and 73 nsec, respectively, if perturbations and cascade from levels $n>4$ can be neglected. (Cascade from $n=4$ states to the $n=3$ level, other than $4f$ cascade, is neglected in the preceding statement because of unfavorable branching ratios.)

Under these same conditions, the $H_8$ radiation should exhibit $4s$, $4p$, and $4d$ decays having lifetimes of 230, 12.4, and 36.5 nsec, respectively.

STARK-EFFECT CONSIDERATIONS

Bethe and Salpeter2 treat Stark mixing of the fine-structure levels in atomic hydrogen by static electric fields. They define a “critical field” as the minimum electric field that will produce full mixing of the states in question. They are particularly concerned with levels of equal $j$ since these states are generally the most sensitive to mixing. It is found from their treatment that critical fields for $3s\rightarrow3p$, $3p\rightarrow3d$, $4s\rightarrow4p$, $4p\rightarrow4d$, and $4d\rightarrow4f$ mixing are approximately 60, 2, 12, 1, and 2/100 V/cm, respectively.

A second Stark-mixing mechanism is the dynamic effect of the passage of charged particles in the presence of the excited atom. Purcell3 has estimated the effect for the $2s$ state. Wilcox and Lamb4 have applied his treatment to the $3s$ state. In Purcell’s approximation, if the given relative velocity of the perturbing charged particle is sufficiently large, the time-varying electric fields will induce a transition rate between electric-dipole-coupled levels that is proportional to the density of charged particles.

APPARATUS

Absolute cross-section measurements were obtained with the electron-impact apparatus used in a previous investigation.5 Spectral isolation was accomplished by using a Jarrell–Ash 500-mm Ebert spectrometer with a spectral slitwidth of about 12 A. An EMI 6095 B photomultiplier was used as the detector.

The time-resolved investigation used the apparatus which has been described by Pendleton and Hughes.5 Spectral isolation was accomplished by using a Bausch & Lomb 500-mm monochromator having a spectral slitwidth of about 20 A. An EMI 6255 B was used for the $H_8$ decay investigation and also for the bulk of the $H_*$ decay investigation. This tube has a response time of about 10 nsec. The turnoff time for the electron beam was typically 8 nsec. (An EMI 9558 B was used for a portion of the $H_*$ study.)

RESULTS

Figure 1 shows the results for the cross-section measurements for $H_*$ and $H_8$ emissions. These emissions were linear with pressure between 3 and 25 mtorr and linear with current between 6 and 100 mA. The beam diameter was generally less than 1 mm. The beam image on the slit was reduced by $\frac{1}{2}$ to insure all wanted radiation being collected.
tion of $\alpha$ and $\eta/\eta_0$. The above argument leads to the prediction that in the low-density limit $F = \frac{1}{2}$. Thus, the velocity autocorrelation function in two dimensions decays as $s^{-1}$ at any finite density, leading to a divergent diffusion coefficient at any nonzero density. This result is in contradiction to previous theories on the density expansion of the diffusion coefficient away from the low-density limit. The study of the late-time autocorrelation function at very low densities by molecular dynamics is unfortunately very difficult since the system must be so large that a molecule undergoes many collisions before a sound wave travels across the size of the system.

The hydrodynamic model, as discussed so far, cannot reverse the velocity of the region initially in motion, and thus cannot reproduce the negative part of the velocity autocorrelation found at high densities. This deficiency can be remedied at least qualitatively by the inclusion of visco-elastic forces in the Navier-Stokes equations. These forces can be obtained from the autocorrelations of the elements of the stress tensor as calculated by molecular dynamics. A trial calculation at $A/A_0 = 1.4$ has shown that negative autocorrelation functions can be obtained in this way, but that at very late times, in agreement with molecular dynamics, the function becomes again positive and decays like $s^{-1}$.

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**Production of H Atoms in the 3s State by the Impact of Fast Ground-State H Atoms on N$_2$**

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Cross sections for the production of hydrogen atoms in the 3s state by the impact of ground-state hydrogen atoms on nitrogen molecules have been measured in the kinetic energy range 10-35 keV. The cross-section curve appears to have a maximum at the lower energies of about $4 \times 10^{-11}$ cm$^2$. This value is roughly $2\frac{1}{2}$ times less than the maximum cross section for producing 3s atoms through electron capture by proton impact on nitrogen molecules in the same energy range.

**INTRODUCTION**

Cross sections have been measured for electron capture into the 3s, 3p, and 3d states by proton impact on N$_2$ in the energy range 10-35 keV.$^1$ In this paper, we report the measurement of the cross section for production of 3s hydrogen atoms by the impact of ground-state hydrogen atoms on N$_2$.

This particular reaction is important in understanding the production of H$_\alpha$ light (n = 3 - 2 transitions) from fast hydrogen atoms in the aurora. Fast protons which are incident on the upper atmosphere will undergo a series of electron capture and stripping reactions as they pass through the atmosphere. These protons will spend much of their fast-particle history in the form of ground-state hydrogen atoms. Hence, collisional excitation of ground-state hydrogen atoms of atmospheric gases could be an important mechanism for the production of the Balmer light, as well as direct electron capture by protons into excited states.
Excitation of the $3^1\,^3D$ and $4^1\,^3F$ Levels of Helium by Direct Electron Impact, and $4^1\,^1P\to4^1\,^3F$ Collisional Transfer

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Excitation of the $3^1\,^3D$ and $3^3\,^3F$ levels of helium by electron impact has been studied by time-resolved spectroscopy of the $3^1\,^3D\to2^1\,^3P(\lambda 6678\,\AA)$ and $3^3\,^3F\to2^3\,^3P(\lambda 5876\,\AA)$ transitions. (Excitation of the $4^1\,^1F$ and $4^3\,^3F$ levels are observed as cascade components under time resolution.) Cross sections are estimated for the direct excitation of these levels by 38-, 50-, and 100-eV electron impact. Excitation of the $4^1\,^1F$ levels by direct electron impact are much larger than predicted by the Born approximation but much smaller than implied by previous experimental measurements. Direct excitation of the $3^1\,^3D$ and $4^1\,^3F$ by 100-eV electron impact is in excellent agreement and satisfactory agreement, respectively, with preliminary close-coupling approximation calculations. The collisional transfer $4^1\,^1P\to4^3\,^3F$ is much smaller relative to the $4^1\,^1P\to4^1\,^3F$ transfer than has previously been suggested.

I. INTRODUCTION

Theoretical cross-section calculations employing the Born and the Born-Oppenheimer approximations yield results which underestimate the excitation of the $3^1\,^3D$ and $3^3\,^3D$ levels by electron impact when compared with experiment. This is the case even at energies where the Born approximation is expected to be valid. In order to make a valid comparison between experiment and theory, however, it is necessary to properly correct the experimental measurements for the effects of secondary excitation processes, such as cascade (radiative transfer from higher states).

Radiative transfer from $F$ states that have been excited by direct electron impact can play an important role in populating the $3^1\,^3D$ levels, according to recent measurements of Jobe and St. John. They obtained very large cross sections for the excitation of the $4^1\,^3F$ levels by electron impact. However, the measurement of $F$-level excitation requires care, since these levels are sensitive to the collisional transfer reaction, $n^1\,^1P\to n^1\,^1F$. This reaction has been previously studied by Kay and Hughes using time-resolved spectroscopy, which is a powerful tool in the analysis of secondary excitation mechanisms. Employing this method, cascading levels can be identified by their characteristic lifetimes, and their contribution to the population of the level in question can be determined absolutely.

This paper describes an experiment in which excitation of the $3^1\,^3D$, $3^3\,^3D$, $4^1\,^3F$, and $4^3\,^3F$ levels by electron impact is measured by applying time-resolved spectroscopy to the $3^1\,^3D\to2^1\,^3P(\lambda 6678\,\AA)$ and $3^3\,^3D\to2^3\,^3P(\lambda 5876\,\AA)$ transitions.

II. EXPERIMENT

The experimental apparatus is comprised of three basic components: (1) an excitation tube, vacuum system, and source of helium atoms; (2) an electron gun to provide a gated electron beam of controlled energy into a field free collision region; and (3) photomultiplier equipment to detect and record the radiative decay of the excited atomic states as a function of time after cessation of electron excitation. A block diagram of the apparatus is shown in Fig. 1. Helium gas is allowed to enter the excitation tube through a cooled trap containing charcoal granules. The excitation tube is sealed off from the vacuum system, and the helium gas pressure is determined by means of a trapped McLeod gauge.

The cathode and grid structure of a 6EM5 beam-power pentode tube are used as an electron gun to provide a sheet beam of monoenergetic electrons. The gun is biased to cut off by application of a negative dc potential on the control grid. A positive pulse, sufficiently large to cause the emission of more than one electron per pulse, is applied to the control grid. The resultant sheet beam is directed by a magnetic field into a collision region, where it collides with the helium gas atoms. The time of flight of the helium ions resulting from the collision is measured by the photomultiplier equipment, and the number of ions is counted to give the cross section.
Some Total Electron-Capture Cross Sections for $\text{H}_2^+$ and $\text{H}_3^+$ Impact on Ne, and $\text{H}_3^+$ on Ar*

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In the process of measuring absolute cross sections for the production of excited hydrogen atoms by fast (20-120 keV) $\text{H}_2^+$ and $\text{H}_3^+$ impact on $\text{H}_2$, $\text{He}$, $\text{Ar}$, and $\text{Ne}$, it was necessary to find out how much an $\text{H}_2^+$ or $\text{H}_3^+$ ion beam would be attenuated in passing through a differentially pumped collision chamber containing the target gas.

In this experiment, ions are produced in an rf ion source, accelerated, and magnetically sorted; they then enter and exit from an electrically grounded collision chamber through apertures $\frac{1}{4}$ in. in diameter and are collected in a Faraday cup. Two chamber lengths, 5.5 and 12.5 cm, were used in the beam-attenuation measurements. The ion beam currents were measured both with and without gas in the individual chambers. There was, of course, a net loss of beam current when gas was...