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STATUS REPORT OF THE FUSION
ALPHA CONFINEMENT TEST--MARCH, 1980

MASTER

BY

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12. 12.12.1968

The leading candidate for a central beam for the diagnostic described in Ref. [1] has been a He^2+ ion produced by accelerating HeI and then stripping it in a gas cell. Recent developments have been extremely encouraging, but the situation has grown more complicated. High current HeI sources now appear feasible, but may not be as useful as previously thought. Further study of both He^2+ and Li^2+ sources and accelerators is needed.

A key question regarding the proposed He^2+ beam was whether the required 1-20 μA beam current could be produced. The highest current reported in the literature was 10 μA , which is, at best, rather weak. However, recent experiments by [2] at Los Alamos for sources developed for the FF central beam project have produced HeI currents of 1 and 4 μA respectively, so the necessary current is attainable with state-of-the-art ion-beam technology.

Several considerations must be taken into account when evaluating these reports for use in the FF beam, but none are drawbacks. Higher voltages are extremely difficult, perhaps impossible. Developments in FF linear accelerators offer promise, although as yet untried, technology for inexpensive high energy accelerators (7-60 MeV).

Recently, it was pointed out in [4] that a substantial portion of the He^2+ formed by the neutralization of HeI^+ would be metastable. This is disadvantageous since the metastable helium is expected to have a higher ionization cross section than the

the total number of particles per unit volume, N , is given by the sum of the number of particles per unit volume, N_1 , in the α phase and the number of particles per unit volume, N_2 , in the β phase, i.e.,

$$N = N_1 + N_2 \quad (1)$$

where N_1 and N_2 are the number of particles per unit volume in the α and β phases, respectively. The number of particles per unit volume in the α phase is given by

$$N_1 = \frac{N}{1 + \frac{V_2}{V_1}} \quad (2)$$

where V_1 and V_2 are the volumes of the

$$V_1 = \frac{V}{1 + \frac{V_2}{V_1}} \quad (3)$$

where V is the total volume.

The number of particles per unit volume in the β phase is given by

$$N_2 = \frac{N}{1 + \frac{V_1}{V_2}} \quad (4)$$

where V_1 and V_2 are the volumes of the

$$V_2 = \frac{V}{1 + \frac{V_1}{V_2}} \quad (5)$$

where V_1 and V_2 are the volumes of the particles per unit volume in the α and β phases, respectively. The number of particles per unit volume in the α phase is given by

The beam of He⁺ generated by the ion source was directed through several foil target sections. The first section was a thin foil of gold, which produced a small amount of secondary electrons from a field-free beta-ray source within the extraction area. This beam was passed through a series of apertures, the density of which could be varied by changing the source heater temperature. The source, which had previously been deuterium, was pulsed for a week or longer to remove the D impurity at the beginning of this experiment. The He⁺ was measured by a momentum analyzer at the center of the beam after the second cell. Since this analyzer was not able to reliably resolve L⁻ from He⁺, a measure of the deuterium contamination was a

On 12/12/68, the subject was interviewed at the New York City Office of the FBI. The subject stated that he had been in the New York City Office of the FBI on 12/12/68, and that he had been interviewed by the New York City Office of the FBI on 12/12/68. The subject stated that he had been in the New York City Office of the FBI on 12/12/68, and that he had been interviewed by the New York City Office of the FBI on 12/12/68. The subject stated that he had been in the New York City Office of the FBI on 12/12/68, and that he had been interviewed by the New York City Office of the FBI on 12/12/68.

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1. The above information is being furnished to you for your information only. It is not intended to constitute an offer of insurance or any other financial product. The information is being provided to you for your information only and should not be used as a basis for any investment decision. The information is being provided to you for your information only and should not be used as a basis for any investment decision.

maximum used in taking the 10.7 kV and 11.7 kV data, and in the 11.7 kV case, it was only about 1 g. Thus, the behavior of the peak curves with sodium density and different electrode area were quite consistent.

The most significant result of this experiment was that high positive to negative ion current conversion efficiency, previously achieved only in a very small scale (1), was obtained in a large scale experiment. Net current in quantities comparable to the beam, although not necessarily of the same sign, appeared at the high conversion efficiency. Scatter was 10-15% at 10.7 kV. The error bars are due to a beam instability which is attributed to variations in the magnitude of the positive ion current density.

From a preliminary analysis of the data, it appears that the conversion efficiency as a function of energy was fairly constant at the 10 kV energy bet. 10.7 and 11.7 kV, but rather at 11.7 kV, dropping even some lower energy which we did not reach. Consequently, it is not clear what would be the optimum energy for this type system. However, other considerations, such as saturation of current density and beam divergence, would warrant looking at higher energies in the 10 - 12 kV range.

It should be pointed out that the net current conversion reached in this experiment do not represent the limit obtainable at these voltages and sodium line densities. This is because a substantial portion of the He^+ current was being neutralized by He^0 gas before it could be neutralized by the sodium. Some ion neutralization by the latter produces significant proportion of

The first stage of the experiment was to determine the effect of the electric field on the motion of the particles. The particles were accelerated by a series of electrodes, and the resulting velocity was measured. The results showed that the velocity of the particles increased as the electric field strength increased. This was expected, as the electric field exerts a force on the charged particles, causing them to accelerate. The next stage of the experiment was to determine the effect of the magnetic field on the motion of the particles. The particles were accelerated by a series of electrodes, and the resulting velocity was measured. The results showed that the velocity of the particles decreased as the magnetic field strength increased. This was unexpected, as the magnetic field exerts a force on the charged particles, causing them to accelerate. The final stage of the experiment was to determine the effect of the combined electric and magnetic fields on the motion of the particles. The particles were accelerated by a series of electrodes, and the resulting velocity was measured. The results showed that the velocity of the particles increased as the combined electric and magnetic field strength increased. This was expected, as the combined electric and magnetic fields exert a force on the charged particles, causing them to accelerate.

acceleration of the beam is still a factor in the design of the capture region. In fact, the capture region must be designed to be able to accept the beam as it is emitted at LAMP, and to be able to capture it.

Several designs will reflect with some loss of efficiency the design of the capture region. With this, it is possible to design a capture region which will be able to accept the beam as it is emitted at LAMP, and to be able to capture it. The design of the capture region will be able to accept the beam as it is emitted at LAMP, and to be able to capture it.

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with the degree of energy variability, the step ΔW will be chosen so that the number of channels is of the order of the number of steps. In the ERL, apparently, this number is about 20, so that ΔW will be 10% of the BE. In the case of low energy beams, however, then the value may perhaps be chosen somewhat smaller, with due regard, for the frequency of the power supply voltage, limiting the final velocity of the particles. A more detailed analysis is necessary for the first BE of the ERL, which is followed by discrete sections which contain resonant structures, and are crossed with slightly increasing velocity by the acceleration.

Either of these accelerators is suited for a multichannel operation. Initially this would be necessary, particularly in the ERL, where it is hard to carry a very small current through the effective acceptance aperture of the BE's with a 20% or larger spread, since it is quite converging beam, and might be able to focus the entire negative ion beam into such an aperture. However, other design considerations imposed by length constraints might dictate several parallel channels, each carrying a smaller current.

Either system has the disadvantage that, in the multichannel mode, the geometric transparency of the entrance plate is necessarily low - probably at most 10-25%. Thus, if a large beam that had passed through a vapor cell were used to enter a multichannel linac, most of the impinging ions would miss the channels and be wasted. Accordingly, multiaperture linacs are best suited for mating to direct extraction sources with

[illegible]

• **Control:**

Either the RFQ or the Megalac might be suitable for our application, and at this point there appears to be no clear basis for a choice between the two. The RFQ appears to be potentially simpler to operate and, with many fewer components, may present fewer alignment and maintenance problems. The Megalac, on the other hand, may pose fewer machining problems, since the RFQ

[illegible]

If we want a He⁺ source, the choice is not obvious on the basis of performance. Either the autoextraction source or the conventional two stage alkali system can probably provide reasonable He⁺ currents. The efficiency of the autoextraction source can perhaps be increased by the use of sodium instead of cesium, since sodium is supposed to produce more He⁺ (²³g) at

the positive ion source. The current density in the positive ion source could also be increased by using a source which was designed for helium positive ion extraction. The source can retain Na^+ ions by making the plasma potential negative with ionizing electrons, so that they do not escape. The sodium jet is designed so that well-defined density layers are formed in the center, which, in principle, results in strong localization of the sodium. Either system, however, will have some metal, representing a definite loss, on the way to the accelerator as a volatile component, so that the alkali atoms can deposit on a surface other than the accelerator.

In terms of instantaneous power consumption, the autoextraction source has a clear advantage. The one presently in use has a total consumption of about 10 kW. On the other hand, the sodium cell used, for the two-stage source, (which is admittedly larger than what we would need) required about 10 kW, while the positive ion source and accelerator used 2.5 kW. The power consumption would be of the greatest concern if the source had to be located at the high voltage end of a single ended electrostatic accelerator.

The autoextraction source is intrinsically simpler than the positive ion-sodium cell system, although the regulation of the alkali layer in the autoextraction source could prove a considerable complication.

An other source is the well known source which preferentially depends to a large extent upon the sort of material to which it is related. If a multiaperture plate with a low extraction plate transparency is used, then the capacity of the ion extraction system of the plate that is provided is reduced. It is also possible to use a plate with a low extraction plate transparency, but with a high extraction plate transparency. In this case, the capacity of the ion extraction system of the plate that is provided is increased. It is also possible to use a plate with a high extraction plate transparency, but with a low extraction plate transparency. In this case, the capacity of the ion extraction system of the plate that is provided is reduced. It is also possible to use a plate with a high extraction plate transparency, but with a high extraction plate transparency. In this case, the capacity of the ion extraction system of the plate that is provided is increased.

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disadvantages, the most significant of which is that the state of the art in Li^+ current production presently is entirely inadequate for our purposes. We expect to require $\sim 100 \text{ mA}$ of Li^+ , while contemporary Li^+ sources produce less than 1 A.

We are presently considering two approaches to the problem of high current Li^+ production. The first of these is a two-stage system consisting of a Li^+ source followed by an electron charge changing cell. A $\text{Li}^+ \rightarrow \text{Li}^0$ conversion efficiency as high as 4.5% has been achieved [1], producing a 4.6 keV Li^0 beam in this design. The simplest Li^+ sources are thermionic, using a surface ionize evaporating lithium. Figure 4 shows a schematic design of such a system, using a porous tungsten cathode and a thermionic emitter. The porous tungsten is coated with lithium, a filament, and supplied with lithium vapor by a reservoir. An alternative for the positive ion stage of this system is a source coated with beta-eucryptite ($\text{Li}_2\text{O} \cdot 2\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$). Either of these thermionic sources should emit $\sim 100 \text{ mA}$ of Li^+ from which it follows that we need an emitter area of $\sim 10 \text{ cm}^2$. Such a large area poses problems if we want to accelerate the Li^+ to only 4.6 keV (to take advantage of the high conversion efficiency), since this makes it difficult to maintain a uniform strong field across the entire emitter. A possible solution is to apply the extraction voltage between the emitter and a fine grid located 0.5-1.0 cm away, thereby making it a planar multiperture source. However, this would decrease the planar transparency, requiring even more emitter area, and to avoid lithium accretion the grid would probably need to be coated.

in the low probability of distortion and the consequent
distortion of the data. An alternate solution is to use a
more complex model, such as the one proposed by the
author, which is more complex and more difficult to
interpret, but which is more likely to be correct. The
author is not aware of any other work in this area.

Aside from the fact that, so far as we are aware, no one has tried to make a LIT source of this sort before, there are at least two significant problems. One is that the electrical insulators maintaining potential differences between the filaments, the wires, and the converter plate will tend to become coated with lithium. Careful attention to shadowing and location of insulators will be necessary to keep potential extraction at an acceptable level. A more subtle problem is that of maintaining a uniform layer of cesium on the converter plate. If it is too thin, it will disappear, or if it forms a full monolayer, the work function of the surface will increase [14], and the field yield will decrease. The amount of cesium on the converter surface will be determined by the balance between a number of factors. In order to avoid condensation of neutral lithium, the surface of the converter will probably be well above the boiling point of cesium (670°), but Cs^+ ions in the discharge will be attracted to it because of its negative bias. Moreover, if it is sufficiently hot ($> 1200^{\circ}\text{C}$), cesium atoms evaporating from its surface will be ionized to Cs^+ [15], which will be attracted back to the plate by the negative bias ($\sim 300\text{V}$). This process will only occur, however, when the amount of cesium on the surface is insufficient to depress the work function below the ionization potential of cesium. Sputtering will, in addition, remove cesium atoms from the plate. Due to the fact that the effective bonding of the cesium decreases as it approaches a full monolayer, and is thus more easily sputtered away, the cesium thickness may tend to be self-regulating at a partial monolayer [16]. If surface

radiation loss by the plasma, although chemical reactions on surfaces by significant quantities would be undesirable.

17. NEUTRALIZER

There are several possible approaches to the neutralizer cell:

(1) Lorentz Detachment of the Extra Electron. This has the disadvantage of requiring excessively high fields. For instance, complete neutralization of He^+ requires an electrostatic field of 350 kV/cm. For a 0.5 MeV He^+ , this would correspond to a magnetic field of 60 kg. If the field must be maintained over an opening of several cm, there will inevitably be a gradient at the entrance. Since ions will traverse different path lengths through the field before they are neutralized they will undergo differing amounts of deflection (the bending radius of a 0.5 MeV He^+ in a 60 kg field is 5 cm), resulting in a dispersion of the beam.

(2) Photo Detachment of the Extra Electron. The outer Electron of He^+ is only bound by .075 eV. However, photodetachment cavities are only attractive for systems with high current densities. A photodetachment cavity for He^+ using CO_2 lasers with 10% efficiency would probably require several megawatts of line power.

(3) Plasma Neutralizer. This is a possibility, but would be difficult to install near the magnetic fields of the torus or in the high potential terminal of a tandem electrostatic accelerator.

4. Alpha-Vapor Neutralizer. The outer, applied electric field, which might result in a larger fraction of the neutralized helium being in the ground state, is not required for neutralization. However, since the neutralizer would be located at a large distance of the target, this would probably result in a neutralizer with a diameter of $\sim 10^3$ cm.

5. Alpha-Neutron Detector. The purpose of this detector is to monitor the beam intensity. It is hoped, at a future date, that we will be able to use a neutron detector, as well as the alpha detector, to monitor the beam intensity. This would be true particularly if the neutron detector were at the terminal of the tubes. However, it is not necessary to have a neutron detector at the target, since the alpha detector would be able to monitor the beam intensity. The neutralizer, located at a large distance from the target, with a continuous stream of vapor, and if a wire mesh particle was neutralized. This profile can, however, easily be circumvented by using a random distribution of the beam intensity, either of which is easily prepared by a random distribution.

1. ANALYZER

In Figure 1, we show a conceptual design of the analyzer to detect the fast $^4\text{He}^{2+}$ resulting from double charge exchange reactions of the doping beam with fusion-product alpha particles. The emerging helium atoms encounter a foil, are stripped (primarily to He^{++}), and the helium ions are magnetically deflected onto energy sensitive solid state detectors. The

principal purpose of the collection is to allow complete
characterization of the direct result of ion-atom impact of the
ion, although it occasionally returns the possibility of
a reaction early as well.

4.1. Ion-Atom Collisional Stripping

As pointed out by Edler and Schuch [16], the
ionization of He by stripping is produced by ion-atom
collision. In this case, the He ion is in the ground state
 $1s^2$. The lifetime of the $1s^2$ state is 1.6×10^{-16} s, while
the $1s^2$ and $1s^2$ ion states have shorter lifetimes
(1.6×10^{-16} s). Since the three $1s^2$ states are parallel, the
quartet states, autoionization occurs and the ionization of
neutral helium, $He(1s^2 2p^1 4p^1)$, only by 1.6×10^{-16} s, is
of the $1s^2$ state. (Hence, the long lifetimes.)

If we consider collisional stripping, $He^+ + A \rightarrow He^{*+} + A^+$,
only the removal of one electron will always leave the He^{*+}
in an excited, triplet state (the remaining two electrons spins
are still parallel). Thus, collisional detachment plus a "spin
flip" must occur if one is to produce ground state helium,

This branching ratio has been measured for He⁺ energies in the
energy range 25 - 400 keV, [17,18]. The ground state yields vary

from 0.6 to 0.8 for H_2 , and 0.5 to 0.6 for other diatomic gases, [17,18]. Our best team will be at an equivalent beam energy of 0.5 MeV, so it is unclear what the ground state yield will be. However, the measured ground state yields all are dropping with increasing energy, and it is possible that at 0.5 MeV the ground state yield will be less than one percent.

Our best team are using the transition ratio between the ground state and the metastable state seems to be measured for a velocity of 1.5 km/sec and for an energy range of 1.5 to 4 KeV for H_2 . There are some questions about the reliability of the "null" interferometer techniques [19,20] for accurately determining the metastable fraction of He+ beams [21], and these uncertainties are largest at low velocities ($< 10^4$ cm/sec). It is more difficult to determine the ground state fraction accurately (which is what we are interested in) at these velocities rather than the metastable fraction, since the ground state has the smaller ionization cross section [22]. The ground state fraction (I_g) and the metastable fraction (I^*) result in relatively large errors in the ground state fraction since $I_g + I^* = 1$.

In addition, one can argue that targets with unpaired electron spins, such as Cs or Na, may have higher ground state yields than systems such as H_2 , N_2 or any of the noble gases, all of which are singlet systems and, therefore, require significant excitation to effect a spin flip. This point should be explored theoretically and experimentally.

At low energies, high ground state fractions are quite feasible. One contributor is Penning ionization, e.g., $\text{He}^*(1s2s) + \text{Ar} \rightarrow \text{He}(1s^2) + \text{Ar}^+ + e^-$, in which the excitation energy of the metastable state is used to ionize the target. This cross section is $\sim 10^{-16} \text{ cm}^2$ at 1eV. Unfortunately no one has investigated reactions such as $\text{He}^-(1s2s2p) + \text{Ar} \rightarrow \text{He}(1s^2) + \text{Ar}^+ + 2e^-$.

A strong E field, in principle, could be used to induce strong coupling between $4p$ and $2i$ states of He^- . However, megagauss fields would be required, and even then a 1-4 MeV $(\text{HeO})^+$ would spend too short a time in a reasonably sized strong field region.

The second point about metastable neutral helium atoms is that their collisional ionization cross sections are likely to be larger than those for the ground state. Approximate proton ionization rate coefficients for 2 MeV He atoms are:

$$k_{\text{ioniz}}^* = k_{\text{ioniz}}(1s2s) = 3 \times 10^{-7} \text{ cm}^3/\text{sec} ,$$

$$k_{\text{ioniz}} = k_{\text{ioniz}}(1s^2) = 2 \times 10^{-8} \text{ cm}^3/\text{sec} .$$

These values are in accord with the ratio of ionization cross sections σ_{0+1}/σ_{01} in a variety of neutral gases. In Figure 7, we see that this ratio ranges from 20 at $E = 20 \text{ keV}$ to 2 at 500 keV, for passage of fast He atoms through H_2 , Ar, He, N_2 and Ne.

for ground state helium, and the double charge transfer cross section for metastable helium and alphas must be "reasonably" large at "reasonably" high velocities ($> 2 \times 10^8$ cm/sec). For the accurate analysis of data, the break-up fraction, the ionization cross sections, and the double charge-exchange cross sections all will have to be measured as accurately as possible. However, since it will be a few years (1984) before TFTR produces alpha particles, there is time to do comprehensive and accurate cross section measurements and calculations.

VII. Li^0 ATOMIC PHYSICS ISSUES

Given the possibility of constructing 5-6 MeV accelerators, Li^0 beams now seem to be quite attractive. The electron affinity of Li^0 may be higher than He^0 [24] by a factor of 2 or 3, although there is some uncertainty in this number due to the lack of absolute yield information. Li^0 can be stripped quite easily, and with moderate efficiency [25]. The proton ionization cross section has been calculated [26], and the double-charge exchange cross section should be at least as large as the one for metastable He^0 since there are two core electrons as well as the loosely bound outer one. At 100-200 keV, the dominant contribution to σ_{ev} in this case should be from the reaction $\text{He}^{++} + \text{Li}^0 \rightarrow \text{He}^0 + \text{Li}^{++} + e^-$. This cross section should be about as large as the $\text{He}^0 + \text{He}^{++} \rightarrow \text{He}^{++} + \text{He}^0$ cross section. Recent calculations by Olson [23] shown in Fig. 8,

11.11. He^{+} ATOMIC EXCITATION LEVELS

Extrapolated yields for neutralizing He^{+} to He^0 at 100 keV He^{+} were estimated to be 1.1×10^{-4} at 100 keV. A further examination of the literature reveals that yields of He^{+} that have been calculated for He^{+} energies in excess of 10 keV are in the vicinity of 10^{-4} with increasing energy so that 1.1×10^{-4} is a conservative estimate. If a 4 MeV accelerator could produce a He^{+} beam of 10^{-4} A at 100 keV, about which is the maximum energy of a structure of 100 kV, however, the required electron beam would be of the order of 4 MeV has not been measured as it would be difficult to produce. He^{+} would be reasonably attractive. Along these lines, it might be possible to enhance the neutral helium yield by irradiation of appropriate target gases of He^{+} .

11.12. He^{+} RADIATIVE RECOMBINATION

It has been suggested [19], that the radiative recombination rate of He^{+} would be enhanced for the fast alphas compared to slow alphas since the 3.5 MeV alphas have the speed of a heavy electron, and the radiative recombination cross section is proportional to $1/v^2$ where v is the relative velocity. If the enhancement were substantial, then one could look for the recombination radiation, appropriately Doppler shifted, and possibly learn much about the fast alpha distribution function without an expensive high energy neutral doping beam. This question is examined in detail in Appendix A by integrating the

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APPENDIX A: RADIATIVE RECOMBINATION FAST ION IN PLASMA

In most plasmas the ions have a mean speed $\sim V_i \ll v_{Te}$, less than that of the electrons, and it is customary to treat electron-ion collisions as if V_i were practically zero. However, this simplification is not correct in fusion plasmas, since the "fast" ions are "lost" with speed $\sim V_i \ll v_{Te}$, and the fast ion distribution is not isotropic. It is, therefore, of interest to know to what extent rates of electron-ion collisions are affected by anisotropy, and here we investigate the problem, which is left as a relative $\sim (V_i/v_{Te})^2$ correction to the isotropic case.

We assume that the electron distribution is a Maxwellian with a mean drift velocity $\mathbf{u}_e$ and a temperature T_e . The ion distribution is assumed to be a Maxwellian with a mean drift velocity $\mathbf{u}_i$ and a temperature T_i . The relative velocity $\mathbf{v}$ is defined as $\mathbf{v} = \mathbf{v}_e - \mathbf{v}_i$, and the relative velocity v is defined as $v = |\mathbf{v}|$. The relative velocity $\mathbf{v}$ is defined as $\mathbf{v} = \mathbf{v}_e - \mathbf{v}_i$, and the relative velocity v is defined as $v = |\mathbf{v}|$.

$$\mathbf{v} = \mathbf{v}_e - \mathbf{v}_i$$

$$v = |\mathbf{v}| = \sqrt{v_e^2 + v_i^2 - 2\mathbf{v}_e \cdot \mathbf{v}_i}$$

The relative velocity $\mathbf{v}$ is defined as $\mathbf{v} = \mathbf{v}_e - \mathbf{v}_i$, and the relative velocity v is defined as $v = |\mathbf{v}|$. The relative velocity $\mathbf{v}$ is defined as $\mathbf{v} = \mathbf{v}_e - \mathbf{v}_i$, and the relative velocity v is defined as $v = |\mathbf{v}|$.

$$\mathbf{v} = \mathbf{v}_e - \mathbf{v}_i \quad (A.1)$$

where $f_1(\vec{v}_1)d\vec{v}_1$ is the distribution of ion velocities. Upon making $\vec{v}_1 \cdot \vec{v}_e = v_1 v_e \cos \theta = v_1 v_e \mu$, in spherical polar coordinates the integral becomes

$$r_n(v_1, T_e) = 2\pi \left(\frac{m_e}{2\pi k T_e} \right)^{3/2} \int_0^{\infty} dv_e \int_{-1}^{+1} dv_e^2 \left[v_e^2 + v_1^2 - 2v_1 v_e \mu \right]^{1/2} \exp \left[-m_e v_e^2 / 2k T_e \right] \quad (3)$$

The hydrogenic recombination cross section is

$$\sigma_n(u) = \frac{A (nh/n)^3 g_n}{(Zm_e u)^2} \left[h/n + 1/2m_e u^2 \right] \quad (4)$$

where the constant $A = 1.6 \times 10^{-17} \text{ cm}^2$, the Gaunt factor g_n is

$$g_n \approx 0.17 n^{2/3} \quad (5)$$

and the ionization potential of level n is

$$h/n = (Z/n)^2 \text{ Rydberg} = 2.2 \times 10^{-11} (Z/n)^2 \text{ erg.} \quad (6)$$

we now define for convenience the dimensionless variable $x = (x_1 - x_0)/\sqrt{2kT_0}$, and the parameters

$$x_n^2 = (x_0 - x_n)/kT_0, \quad x_1^2 = (x_0 - x_1)^2/2kT_0. \quad (8)$$

After direct integration of Eq. (8) one obtains the function $\psi(x_1, y_n)$ with the result

$$\psi(x_1, y_n) = \frac{4 \sqrt{2\pi} \sqrt{y_n}}{\sqrt{2\pi} \sqrt{y_n}} \frac{e^{-x_1^2/2}}{2 \sqrt{kT_0}} \left[\operatorname{arctg} \frac{x_1 + x_n}{y_n} \right].$$

the quantity I being

$$I(x_1, y_n) = \frac{1}{x_1 y_n} \int_{-x_1}^{x_1} dx \cdot x \cdot \exp(-x^2) \left[\operatorname{arctg} \frac{(x+x_1)^2 + y_n^2}{y_n} \right] =$$

$$= \operatorname{arctg} \left[\frac{(x+x_1)^2 + y_n^2}{y_n} \right] \Big|_{-x_1}^{x_1}. \quad (9)$$

By splitting this integral into two terms, viz $\int_{-x_1}^{x_1} \frac{(x_1 - x)}{y_n} \exp(-x^2) \operatorname{arctg}(\cdot)$, a change of variable reduces Eq. (9) to

$$x_1 y_n I(x_1, y_n) = \int_0^{x_1} dy \cdot y_n (y_n^2 - x_1^2) \exp[-(x_1 - y_n)^2] \operatorname{arctg}(\cdot) +$$

$$+ \int_0^{x_1} dy \cdot y_n (y_n^2 + x_1^2) \exp[-(x_1 + y_n)^2] \operatorname{arctg}(\cdot), \quad (10)$$

where, in integration by parts yields

$$I(x_i, y_n) = \frac{\exp(-x_i^2)}{x_i} \int_0^{\infty} dt \left[\frac{\exp(-t^2) \sinh(2tx_i)}{y_n^2 + t^2} \right] \quad (11)$$

this integral can be evaluated term by term, and we obtain

$$\begin{aligned} I(x_i, y_n) &= \exp(-x_i^2) \left[\sum_{m=0}^{\infty} \frac{(-4x_i^2 y_n^2)^m}{(2m+1)!} I(0, y_n) \right. \\ &\quad \left. + \sum_{m=1}^{\infty} \frac{(-4x_i^2 y_n^2)^m}{(2m+1)!} \sum_{k=1}^m \frac{(k-1)!}{(-y_n^2)^k} \right] \\ &= \exp(-x_i^2) \left[\frac{\sin(2x_i y_n)}{(2x_i y_n)} I(0, y_n) \right. \\ &\quad \left. + \sum_{m=1}^{\infty} \frac{(-4x_i^2 y_n^2)^m}{(2m+1)!} \sum_{k=1}^m \frac{(k-1)!}{(-y_n^2)^k} \right] \quad (12) \end{aligned}$$

where

$$\begin{aligned} I(0, y_n) &= \lim_{x_i \rightarrow 0} I(x_i, y_n) = \int_0^{\infty} dt \left[\frac{\exp(-t^2)}{t + y_n^2} \right] \\ &= \exp(y_n^2) E_1(y_n^2) \quad (13) \end{aligned}$$

I_1 being the first exponential integral. Together, Eqs. (11), (12), and (13) provide the desired result. It is readily verified that, in the limit $x_1 \rightarrow 0$, the standard hydrogenic formula is regained.

In fusion plasmas, the parameter $Y_0 \ll 1$, and so ka_1 is the relevant term of the second summation in Eqs. (12). Moreover, for α -particles produced in the D-D reaction, the parameter $x_1 \approx x = (0.1 \text{ keV}/T_0)^{1/2} \ll 1$. It follows, then, that the asymptotic approximation of the coefficient $C_n(x_1, T_0)$ is

$$\frac{C_n(x_1, T_0)}{C_1(x_1, T_0)} = \exp(-x_1^2) \left[1 + \frac{2x_1^2}{3 \ln(Y_0^2)} \right]. \quad (14)$$

The qualitative behavior of this ratio is the same as the ratio of the number of electrons in each state ($n_1 = 1$, and $v_1 \ll 1$) that, relative to the ion, have a speed smaller than some maximum value v_0 for efficient recombination. We can use this result over all bound states n and obtain the complete rate coefficient

$$\begin{aligned} C(x_1, T_0) &= \sum_{n=1}^{\infty} C_n(x_1, T_0) \\ &= \exp(-x_1^2) \left[\sum_{n=1}^{\infty} C_n(T_0) + 3.4 \cdot 10^{-5} \exp \left(\frac{3}{2} \ln^2 Y_0^{-1} \right) x_1^2 \right] \\ &= \quad \quad \quad (15) \end{aligned}$$

Typical numerical values are $x = 0.14$ for $Y_0^2 = 1$, so that

reduction in the α -particle radiative recombination rate coefficient is small, $\bar{S}(x_1, T_e) / \bar{S}(0, T_e) \approx 0.96$.

- [20] J. Kantor, L. Mir, and B. Rosner, Charge States of Fragments of the HeH^+ Ion After a Dissociative Single Collision in the 500 to 900 keV Energy Range, Technion PH-79-52, Haifa, Israel
- [21] Ed Gerjuico, (private communication)

internal layer of the collector (without the 10^{-4} cm thick 10^{-4} cm thick) in the discharge jet with 10^{-4} cm.

Fig. 7. The ionized $^4\text{He}^0$ fusion products enter the collector through a foil, which strips most of their 10^{-4} cm thick, and are then magnetically collected onto a foil with a resolution with energy, resolution. The shape of the peak, as well as the yield as a function of the energy, give information about the alpha particle density, and velocity distribution in the plasma.

Fig. 8. Ratio of metastable to ground state attenuation cross sections for helium as a function of helium energy for a variety of target gases, taken from Pedersen [15].

Fig. 9. Double charge transfer cross sections for He^{++} and He^+ as a function of energy. The points are experimentally referenced in [15]. The solid line is an estimate for metastable helium. The solid line on right is a recent calculation by Olson [23] for $\text{Li}^0 + \text{He}^{++} \rightarrow \text{He}^0 + \text{Li}^{++}$.

Fig. 10. Double charge transfer cross section for He^{++} and He^+ , taken from [15].

Fig. 11. Double charge transfer cross section for He^{++} and He^+ , taken from [15].

Fig. 11. Reaction rate calculations for classical alpha particle distribution functions as defined in (1), and the cross sections for He^+ , He^- and He^0 as given in Eqs. (2) and (3).

Fig. 12. The "differential reaction rate" as defined in (1), for He^+ and He^0 for various angles to the beam and for various velocities $v = v/v_1$ where $v_1 = 1.1 \times 10^8 \text{ cm/sec}$.

QUESTION 1

QUESTION	ANSWER	MARKS	STATUS
1. The following table shows the number of students who achieved different grades in a mathematics examination. Calculate the mean grade.	<p>Grade: 1, 2, 3, 4, 5</p> <p>Number of students: 10, 15, 20, 25, 30</p> <p>Mean grade = $\frac{1 \times 10 + 2 \times 15 + 3 \times 20 + 4 \times 25 + 5 \times 30}{10 + 15 + 20 + 25 + 30}$</p> <p>Mean grade = $\frac{10 + 30 + 60 + 100 + 150}{100}$</p> <p>Mean grade = $\frac{350}{100}$</p> <p>Mean grade = 3.5</p>	10	Correct
2. A class of 30 students took a test. The scores were: 10, 12, 15, 18, 20, 22, 25, 28, 30, 32, 35, 38, 40, 42, 45, 48, 50, 52, 55, 58, 60, 62, 65, 68, 70, 72, 75, 78, 80. Calculate the median score.	<p>Median score = $\frac{30 + 32}{2}$</p> <p>Median score = $\frac{62}{2}$</p> <p>Median score = 31</p>	10	Correct
3. A group of 50 students took a test. The scores were: 10, 12, 15, 18, 20, 22, 25, 28, 30, 32, 35, 38, 40, 42, 45, 48, 50, 52, 55, 58, 60, 62, 65, 68, 70, 72, 75, 78, 80, 82, 85, 88, 90, 92, 95, 98, 100. Calculate the range of the scores.	<p>Range = $100 - 10$</p> <p>Range = 90</p>	10	Correct
4. A group of 50 students took a test. The scores were: 10, 12, 15, 18, 20, 22, 25, 28, 30, 32, 35, 38, 40, 42, 45, 48, 50, 52, 55, 58, 60, 62, 65, 68, 70, 72, 75, 78, 80, 82, 85, 88, 90, 92, 95, 98, 100. Calculate the mode of the scores.	<p>Mode = 100</p>	10	Correct
5. A group of 50 students took a test. The scores were: 10, 12, 15, 18, 20, 22, 25, 28, 30, 32, 35, 38, 40, 42, 45, 48, 50, 52, 55, 58, 60, 62, 65, 68, 70, 72, 75, 78, 80, 82, 85, 88, 90, 92, 95, 98, 100. Calculate the standard deviation of the scores.	<p>Standard deviation = 10</p>	10	Correct

TABLE II. A ${}^3\text{He}$ Beam
Advantages and Disadvantages of ${}^3\text{He}$ Beam

Advantages	Disadvantages
<p>Two ways to make many mA of He^-.</p> <p>The direct extraction He^- source is quite simple.</p> <p>Does not coat insulators, although associated Na or Cs may.</p> <p>Easy to make high intensity He^+ arc.</p> <p>3 MeV accelerators cheaper than 6 MeV accelerators.</p>	<p>An unknown but probably large percentage of the He^0 beam resulting from stripping He^- will be in a long-lived metastable state.</p> <p>σ_{He^+} on He^{++} not known, and very difficult to measure.</p> <p>Need more information on ionization losses of entering He^-.</p> <p>A significant percentage of the He^0 resulting from double charge exchange may be in metastable state. Resulting ionization losses complicate data analysis.</p> <p>He is hard to pump; this leads to losses in production of He^- and in acceleration.</p> <p>A He^- accelerator will not accelerate Li^- to the required energy.</p>

TABLE III. A Li Beam

Advantages and Disadvantages of a Li Beam

Advantages	Disadvantages
easy to pump (no vacuum problem in acceleration)	Cells exposed outside: required shielding of insulators. However, He may present similar problems because of presence of He^{+} ions.
excite Li^{+} to $n=2$ in ground state.	
expect some He^{+} ions. Bubble chamber technique to relatively easily to ground state on time scale faster than ionization time. This simplifies interpretation of emerging He^{+} flux.	don't want have to make beam in penetrating plasma, more involved with He.
ionization and He^{+} and neutralization efficiency are relatively easily measured.	ionization and He^{+} not known. Ionization efficiency not known. It should be $\sim 10^{-4}$.
linear that accelerates Li^{+} can also accelerate He^{+} .	how to make He^{+} source. For Li^{+} at 10^6 V, can only get 1-2 mA or 10 to 20% of plasma.
	Electrostatic accelerator probably cannot be built.

TABLE IV. Atomic Physics Needs

Reaction.	Quantity	Energy	Difficulty
$\text{He}^+ + \text{p} \rightarrow \text{He}^+, \text{He}^{++} \dots$	$^1\text{0}^+1, ^1\text{0}^+2$	0.5-3MeV	Experiment hard, theory not too difficult.
$\text{He}^- + \text{A}^0 \rightarrow \text{He}^0 \text{ or } \text{He}^*$	Ground state and metastable yield	0.5-3MeV	Experiment not too difficult, theory (should try to calculate)
$\text{He}^+ + \text{He}^{++} \rightarrow \text{He}^0 \text{ or } \text{He}^*$	$^1\text{20}, ^1\text{20}^*$	10-500keV	Experiment not too difficult, theory
$\text{Li}^0 + \text{He}^{++} \rightarrow \text{He}^0$	$^1\text{20}, ^1\text{20}^*$	10-500keV	Experiment not too difficult, theory-
$\text{Li}^- + \text{A}^0 \rightarrow \text{Li}^0$	Neutral yield $^1\text{20}, ^1\text{21}$	1-6MeV	Experiment not too difficult, theory-
$\text{Li}^+ + \text{A}^0 \rightarrow \text{Li}^-$	Li^- yield	1-6MeV	Experiment not too difficult, theory-
$\text{HeH}^+ + \text{A}^0 \rightarrow \text{HeH}^0$	HeH^0 yield	1-6MeV	Experiment not too difficult, theory-

13. English 14. History 15. Geography 16. Art 17. Music 18. Physical Education 19. Health 20. Computer Science 21. Foreign Languages 22. Career Education 23. Life Skills 24. Environmental Studies 25. Public Safety 26. Consumer Education 27. Financial Literacy 28. Civic Education 29. Leadership 30. Entrepreneurship 31. Project Management 32. Teamwork 33. Communication 34. Problem Solving 35. Critical Thinking 36. Decision Making 37. Time Management 38. Stress Management 39. Self-Management 40. Goal Setting 41. Planning 42. Organization 43. Prioritization 44. Delegation 45. Collaboration 46. Conflict Resolution 47. Negotiation 48. Persuasion 49. Influence 50. Motivation 51. Inspiration 52. Creativity 53. Innovation 54. Risk Taking 55. Resilience 56. Adaptability 57. Flexibility 58. Openness 59. Curiosity 60. Enthusiasm 61. Passion 62. Commitment 63. Dedication 64. Persistence 65. Perseverance 66. Determination 67. Resolve 68. Willpower 69. Discipline 70. Self-Control 71. Responsibility 72. Accountability 73. Integrity 74. Honesty 75. Trustworthiness 76. Reliability 77. Dependability 78. Consistency 79. Stability 80. Endurance 81. Stamina 82. Strength 83. Power 84. Influence 85. Authority 86. Leadership 87. Management 88. Supervision 89. Direction 90. Guidance 91. Instruction 92. Teaching 93. Coaching 94. Mentoring 95. Tutoring 96. Training 97. Education 98. Learning 99. Development 100. Growth 101. Progress 102. Achievement 103. Success 104. Accomplishment 105. Attainment 106. Realization 107. Fulfillment 108. Satisfaction 109. Contentment 110. Happiness 111. Joy 112. Pleasure 113. Fun 114. Entertainment 115. Recreation 116. Leisure 117. Relaxation 118. Rest 119. Sleep 120. Health 121. Wellness 122. Fitness 123. Exercise 124. Activity 125. Movement 126. Action 127. Behavior 128. Conduct 129. Character 130. Personality 131. Temperament 132. Manner 133. Demeanor 134. Bearing 135. Posture 136. Gait 137. Walk 138. Run 139. Jump 140. Leap 141. Bound 142. Skip 143. Hop 144. Stomp 145. Kick 146. Push 147. Pull 148. Drag 149. Drag 150. Drag

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The diagram illustrates the transport and acceleration of a negative ion beam. The beam originates from a Direct Extraction Negative Ion Source, passes through a Deflection Magnet, and is focused by a Converter Plate Curved To Focus Negative Ions In X Direction (Cross Over In Magnet). It then travels through a Pumpout Region and two Einzel Lens sections (X Plane and Y Plane). The beam is then accelerated by an RF Quadrupole Accelerator (LASL) and deflected by a Bending Magnet. Finally, it passes through a Neutralizer and Cryocondensation Pumping system.

Figure 10. Main components of a negative ion beam transport line. At each stage, provided by Beam Dynamics.

CONCEPTUAL DESIGN OF TWO-FASE EXTRACTION

Fig. 1. Conceptual design of a two-phase extraction system. The Li boiler extracts the Li ions, which are then extracted by the porous tungsten disk. The Li ions are then extracted by the Li boiler, which is connected to the hot walls. The hot walls are connected to the cold surface, which is connected to the anode and magnet. The anode and magnet are connected to the metal vapor trap, which is connected to the hot neutral metal vapor trap. The hot neutral metal vapor trap is connected to the accelerator.

The diagram illustrates the internal structure and components of a vacuum tube assembly, likely a magnetron. The diagram shows a circular arrangement of components, including the Inverter Plate, High Voltage Insulator, and various internal structures. Labels in English and Hebrew identify the parts:

- Top Labels:**
 - מגנטרון (Magnetron)
 - פלטת אינברטר (Inverter Plate)
 - עازل מתח גבוה (High Voltage Insulator)
- Left Labels:**
 - פלטת אינברטר (Inverter Plate)
 - עازل מתח גבוה (High Voltage Insulator)
 - משני, 3000V (Secondary, 3000V)
- Right Labels:**
 - עازل מתח גבוה (High Voltage Insulator)
 - מגנטרון (Magnetron)
- Bottom Labels:**
 - מגנטרון (Magnetron)
 - פלטת אינברטר (Inverter Plate)
 - עازل מתח גבוה (High Voltage Insulator)

PRELIMINARY CONCEPTUAL DESIGN OF NON-THERMAL NEUTRAL HELIUM ANALYZER

Note:

Stripped Helium Ions are Magnetically
Deflected to Effect Shielding of
Detectors and Momentum Analysis

Fig. 6. The neutralized Helium ions produced by the neutralization cell, which strips most of the 4He^{++} ions, are then magnetically deflected onto solid state detectors with energy resolution. The shape and energy of the peak, as well as the time of arrival of the peak energy, give information about the temperature and ionized velocity distribution in the plasma. (cont.)

Fig. 2. Ratio of total photoionization cross-section to ground state photoionization cross-section as a function of energy for various target gases, taken from reference [1].

Fig. 8. Total cross section for He^{2+} ions. The solid line is the $\text{He}^{2+}-e$ cross section, the dashed line is the $\text{He}^{2+}-\text{He}$ cross section. The data points are from the literature. The data points are from the literature. The data points are from the literature.

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-e

-a

-e

-4