# Muon catalysis in a dense inhomogeneous plasma

L. I. Men'shikov and V. A. Shakirov

*I. V. Kurchatov Institute of Atomic Energy, Academy of Sciences of the USSR, Moscow and Power Institute, Obninsk*

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Elementary muon catalysis processes in deuterium and tritium plasmas are discussed. It is shown that, in plasmas with temperature $T\sim 100$ eV and density $\sim 10^{22}$ nuclei·cm$^{-3}$, in which about 5% of the medium is in the form of dense cold drops ($T\leqslant 2$ eV), the number of muon catalysis cycles is up to about 300–500. Some mechanisms of muon stripping from $\alpha\mu$ ions are examined. Attention is drawn to the advantages of $Z$-pinches.

## 1. MESOATOMIC AND MESOMOLECULAR PROCESSES IN PLASMAS

One of the main muon-loss channels in muon catalysis reactions in $d$–$t$ mixtures is the attachment of the muon to the $\alpha$ particle during the fusion reaction in the mesic molecule:

$$dt\mu \begin{cases} \xrightarrow{\omega_s^0} \alpha\mu + n \\ \xrightarrow{1-\omega_s^0} \alpha + \mu + n \end{cases} + 17.6\ \text{MeV}, \tag{1}$$

where $\omega_s^0 = 0.00845$ (Ref. 1). Some of the muons bound to the $\alpha$ particles are stripped off as the $\alpha\mu$ slows down in the medium, so that the sticking coefficient is

$$\omega_s=\omega_s^0(1-R),$$

where $R$ is the stripping probability. For cold (molecular) $d$–$t$ mixtures, the experiment described in Ref. 2 gives

$$\omega_s=0.0045\pm0.0005. \tag{2}$$

The theoretical value of $\varphi = 1$ is somewhat higher:

$$\omega_s=0.006\ [1, 3]\ ;\ 0.0054\pm0.0006\ [4]\ ;\ 0.0054\ [5], \tag{3}$$

where here and in what follows $\varphi = N/N_0$, $N$, $N_0 = 4.25\cdot 10^{22}$ cm$^{-3}$ is the number of nuclei in 1 cm$^3$ of the mixture and of liquid hydrogen, respectively.

New muon stripping mechanisms are proposed in Ref. 6, and it is noted that it is, in principle, possible to increase substantially the number of muon catalysis cycles in the $d$–$t$ plasma. In particular, it is found that $\omega_s$ decreases with increasing plasma temperature. This phenomenon is a manifestation of the Belyaev-Budker effect:[7] the Coulomb interaction ensures that electrons with velocities greater than that of a charged particle traveling in plasma produce practically no contribution to the friction force $F_{\rm fr}$ acting on the particle. Consequently, $F_{\rm fr}$ decreases with increasing temperature, i.e., there is an increase in the number of collisions with plasma nuclei $X = d, t$

$$\alpha\mu + X \xrightarrow{\sigma_s} \begin{cases} \alpha + \mu X, & (4) \\ \alpha + \mu + X, & (4a) \end{cases}$$

in which $\alpha\mu$ loses the muon. The reduction in $F_{\rm fr}$ with increasing temperature is clear from Fig. 1, which shows the acceleration $dv/dt = F_{\rm fr}/m_{\alpha\mu}$ of the $\alpha\mu$ ion for $\varphi = 1$ as a function of $v$ (in atomic units; $t$ is in seconds).

The rate $\lambda_{dt\mu}$ of production of mesic molecules $dt\mu$ is high ($\gtrsim 10^9$ s$^{-1}$) for $T\leqslant T_m\sim 2$ eV (Refs. 8 and 6), and the probability $\omega_s$ is small for $T\gtrsim T_c$ (Ref. 6), where

$$T_c=100-500\ \text{eV}. \tag{5}$$

The difference between $T_m$ and $T_c$ is large, so that, in a homogeneous plasma, the increase in the number of muon catalysis cycles is only up to $X_c\approx 200$. It was suggested in Ref. 6 that a more substantial increase in $X_c$ could be achieved by muon catalysis in inhomogeneous plasma consisting of cold ($T\lesssim T_m$) drops surrounded by hot ($T\gtrsim T_c$) plasma. The nuclear reactions then occur within the drops and, if the drop radius $r$ is less than half the slowing-down length of the $\alpha\mu$ ions (here and below, length and time are given in centimeters and seconds, respectively), i.e.,

$$r\leqslant 0.02/\varphi_m \tag{6}$$

where $\varphi_m$ is the density of the medium in the drops, the $\alpha\mu$ ions will freely leave the drops and lose their muons as they slow down in hot plasma.

It follows that both $\omega_s$ and $1/\lambda_{dt\mu}$ can be made small simultaneously in inhomogeneous plasma. Here we can see an analogy with the chain reaction in natural uranium. It is well known that this reaction is impossible in homogeneous reactors, and can be accomplished only in heterogeneous systems.

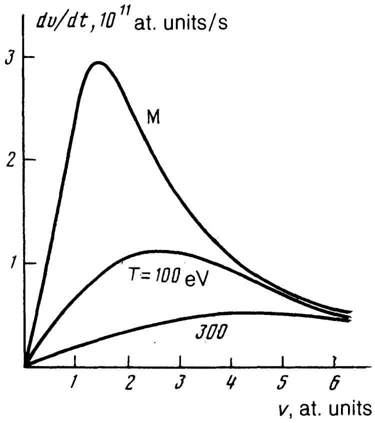


FIG. 1. The acceleration $dv/dt$ as a function of the velocity $v$ of the $\alpha\mu$ ion at plasma temperatures of 100 and 300 eV. The curve marked $M$ corresponds to the molecular medium.

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When $T \gtrsim 150$ eV, the range $l_{ph}$ of bremsstrahlung photons in a drop is comparable with $r$, so that the temperature within the drop rapidly increases and $\lambda_{dt\mu}$ falls. In the opposite limit ($T \lesssim 150$ eV), the photons are absorbed near the surface of the drop in photionization processes of the from $\gamma + D \to D^+ + e$, and in free-free transitions of the form $\gamma + e + X \to e' + X$. The range $l_{ph}$ is then small near the surface of the drop, and we have equilibrium radiation. The radiative heat flux is small in comparison with the heat transported by electrons. The drop is thus effectively shielded from electrons by the "jacket" of evaporating material. The evaporation lifetime of the drop can be found from the condition that the heat supplied by electrons and the heat removed by evaporating material are equal:[6]

$$\tau_{ev} = 25\, N_m r^2/4\varkappa \approx 2.8 \cdot 10^{-5} \varphi_m r^2 (\tilde{T})^{-5/2}, \tag{7}$$

where $\varkappa$ is the thermal conductivity of the plasma and $\tilde{T} = T$ (keV).

Because the thermal conductivity of the drop material is low, heat does not succeed in penetrating the drop in a time $\sim \tau_{ev}$.

Muon catalysis in inhomogeneous plasma is thus possible provided

$$T_c \lesssim 150 \text{ eV}. \tag{8}$$

The conclusion from (5) and (8) is that we have to improve the value of $T_c$.

The uncertainty in $T_c$ [see (5)] is due to the fact that we do not know the cross section for the process (4a) near the threshold. We also do not know the contribution of stepwise ionization processes $(\alpha\mu)_{1s} \to (\alpha\mu)_n \to \alpha + \mu$, to the muon stripping probability $R$, where $n$ is the principal quantum number of the $\alpha\mu$ ion.

The cross section $\sigma_s$ for reaction (4) is found in Refs. 3–5 and 9 from the cross section $\sigma_e$ for the analogous electron process ($He^+ + p \to \cdots$):

$$\sigma_s(v) = (m_e/m_\mu)^2 \sigma_e(v) \equiv \tilde{\sigma}_s(v).$$

In reality, the cross section is much greater near the threshold ($v \approx v_{th} \approx 0.5$ a.u.):

$$\sigma_s(v) = \tilde{\sigma}_s(v) g(v), \quad g_0 \equiv g(v_{th}) = 10-50, \tag{9}$$

which is explained by nonadiabatic effects.[10] This formula is confirmed indirectly by experiments[2] with the molecular $d$–$t$ mixture. Actually, the theoretical value of $\omega_s$ given by (3) agrees with the experimental value (2) if we assume that, for $v < v_{max} \approx 1.6$ a.u., for which the uncertainty in $\sigma_s$ is a maximum, the estimate given by (9) is valid (the cross section $\sigma_e(v)$ is a maximum for $v = v_{max}$ $\sigma_e(v_{max}) = \max$).

The aim of this paper is to use $\omega_s$, calculated with allowance for stepwise ionization (Sec. 2), to predict the number of cycles that can be achieved in inhomogeneous plasma (Sec. 3), and to predict the typical parameters of such plasma. In Sec. 4, we examine the energy balance of the "drop" muon catalysis and, finally, in Sec. 5, we discuss our results.

## 2. MUON STICKING DURING THE SLOWING DOWN OF $\alpha\mu$ IONS IN PLASMA

To calculate the muon stripping probability $R$, we must solve the set of equations for the level populations of the mesic ion $\alpha\mu$, taking into account all possible transitions of the muon when the mesic ion is scattered (4) by the plasma nuclei and electrons:

$$\frac{dN_n}{dt} = -\Big(\lambda_{nc} + \sum_{n'} \lambda_{nn'}\Big) N_n + \sum_{n'} \lambda_{n'n} N_{n'},$$
$$\frac{dN_c}{dt} = \sum_n \lambda_{nc} N_n. \tag{10}$$

where $N_n$ and $N_c$ are the populations of bound states $(\alpha\mu)_n$ and of the continuum, and $\lambda_{nn'}$ is the $n \to n'$ transition rate. Following Refs. 3–5 and 9, we transform the variable $t$ to the rate

$$\frac{dN_n(t)}{dt} = \frac{dv}{dt}\frac{dN_n(v)}{dv}.$$

To calculate $dv/dt$ (Fig. 1), we use the well known formula for the stopping power of plasma:[11]

$$\frac{dv}{dt} = -\frac{4\pi e^4 N \Lambda}{m_e m_{\alpha\mu} v^2} \mu\left(v\left(\frac{m_e}{2T}\right)^{1/2}\right),$$
$$\mu(x) = \frac{2}{\pi^{1/2}}\left(\int_0^x e^{-y^2} dy - x e^{-x^2}\right), \tag{11}$$

where

$$\Lambda = \ln(m_e v r_D/\hbar), \quad r_D = [T/(8\pi N e^2)]^{1/2}.$$

Equations (10) were solved numerically, subject to the initial conditions given in Ref. 1. The following processes were taken into account: ionization and charge transfer, stepwise excitation and deexcitation, Auger effect on plasma electrons, and radiative transitions in the mesic ion $\alpha\mu$. Experimental data reported in Refs. 12–14 were used in (9) for $\sigma_e(v)$. The calculation of $R = N_c(t = +\infty)$ and $\omega_s$ was performed for three cases (Figs. 2 and 3), namely, $g_0 = 1$, $g_0 = 10$, and $g_0 = 50$. For $g_0 = 1$, we have $\sigma_s = \tilde{\sigma}_s$. The case $g_0 = 10$ corresponds to $\sigma_s = \tilde{\sigma}_s$ for $v > v_{max}$ and to $\sigma_s \approx \tilde{\sigma}_s(v_{max}) = \text{const}$ for $v < v_{max}$ Finally, for $g_0 = 50$, we assume that $\sigma_s = \tilde{\sigma}_s$ for $v > v_{max}$ and $\sigma_s = 5\tilde{\sigma}_s(v_{max}) = \text{const}$ for $v < v_{max}$.

The numbers 1, 2, 3 shown against the curves in Figs. 2 and 3 correspond to the above three values of $g_0$. We empha-

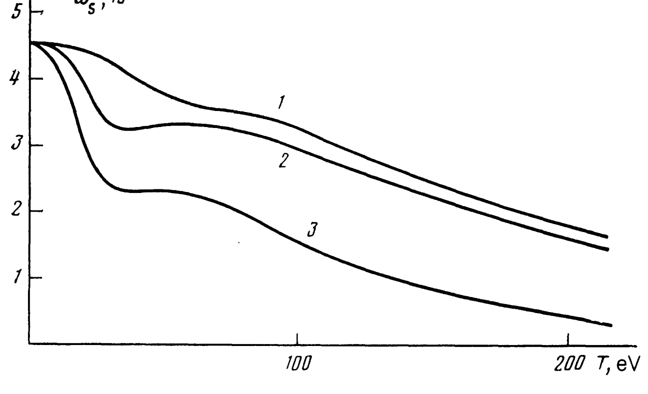


FIG. 2. Temperature dependence of $\omega_s$ for $\varphi = 1$ and different values of the sticking cross section $\sigma_s$ (Sec. 2).

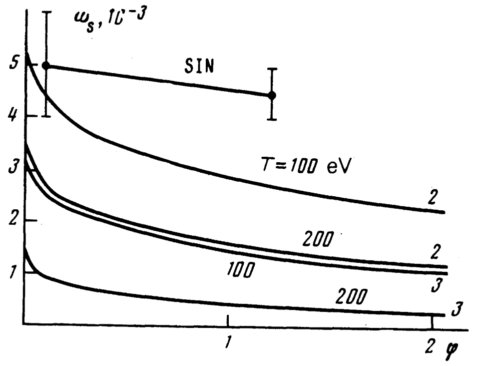


FIG. 3. Sticking coefficient $\omega_s$ as a function of $\varphi$ for $T=100$ eV and 200 eV and different $\sigma_s$ (Sec. 2). The curve marked SIN represents the experimental results[2] for the molecular medium.

size that, according to (9), the true sticking coefficient $\omega_s$ lies in the range

$$\omega_s^{(2)} \leqslant \omega_s \leqslant \omega_s^{(3)}. \tag{12}$$

Figure 3 shows $\omega_s$ as a function $\varphi$ for different $T$ (in eV). The curve marked SIN corresponds to the experimental[2] sticking coefficient in cold (molecular) $d$–$t$ mixture.

Figures 4–6 show some interesting properties of muon stripping during the slowing down of $\alpha\mu$ ions in plasma for $g_0 = 1$.

Figure 4 shows the sticking probability $R$ as a function of the number $n_{\max}$ of Rydberg states $(\alpha\mu)_n$ taken into account in the plasma and in the molecular medium. It is clear that stripping from levels with $n \lesssim 5$ plays the dominant part.

Figure 5 shows the population $N_1$ (curves 1 and 2) and $N_c$ (curves 3 and 4) of the ground state ($n = 1$) and of the continuum as functions of $v$ in the molecular medium (curves 1 and 4) with $\varphi = 1$ and in plasma (curves 2 and 3) with $\varphi = 1$ and $T = 100$ eV.

Figure 6 shows $F(v) = \lambda_{1c}(dv/dt)^{-1}$ as a function of $v$. It illustrates stripping from the 1$s$ state ($n = 1$). If we take into account only the 1$s$ state of the $\alpha\mu$ ion, we find that

$$R=1-\exp\left(-\int_0^{v_0} F(v)\,dv\right),$$

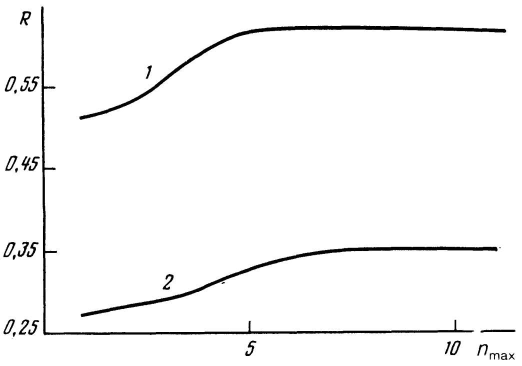


FIG. 4. Muon stripping probability $R$ as a function of the maximum principal quantum number $n_{\max}$ of Rydberg states of the $\alpha\mu$ ion taken into account for $g_0 = 1$ (Sec. 2). Curves 1 and 2 correspond to the molecular medium with $\varphi = 1$ and plasma with $\varphi = 1$ and $T = 100$ eV.

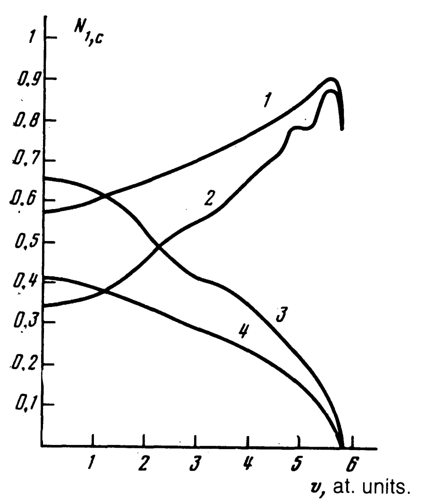


FIG. 5. The ground state and continuum populations $N_1$ and $N_c$ in molecular medium and in plasma as functions of the $\alpha\mu$ ion velocity $v$.

where $v_0 = 5.8$ a.u. is the initial velocity of the $\alpha\mu$ ion. The numbers shown against the curves are the plasma temperature in electron volts. The $T = 0$ curve corresponds to the molecular medium. We note that, in the approximation of a single state, $R$ is a slowly varying function of $\varphi$. Figure 6 shows that, when $T \sim 100$ eV, the function $F(v)$ has a sharp peak at small values of $v$, i.e., at the end of the slowing down path of the $\alpha\mu$ ion.

We recall in conclusion that for $g_0 = 1$, which corresponds to Figs. 4–6, the sticking probability is underestimated [see (12)]. In particular, the peak in Fig. 6 is actually sharper. Nonadiabatic effects were ignored in all calculations concerned with the $1 \to n$ transitions, which tends to increase $\lambda_{1n\gamma}$, i.e., additionally reduce $\omega_s$.

## 3. MUON CATALYSIS KINETICS IN AN INHOMOGENEOUS MEDIUM

It follows from Figs. 2 and 3 that $\omega_s$ is relatively small for

$$T \leqslant 100 \text{ eV}, \tag{13}$$

i.e., the criterion given by (8) is satisfied. The plasma density must be high enough, i.e.,

$$\varphi_c \geqslant 0.2. \tag{14}$$

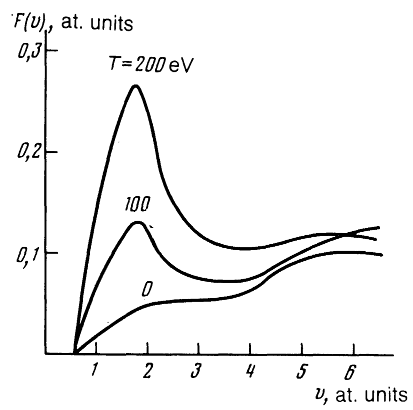


FIG. 6. The function $F(v)$.

Actually, this density corresponds to the lowest muon "energy cost" $Q_\mu \approx 2$ GeV (Refs. 15 and 16; see also Sec. 4), and stepwise ionization ensures that $\omega_s$ is small (see. Fig. 2).

When conditions (13) and (14) are satisfied, the plasma pressure is of the order of $p \sim 10^6$ atm. If we use the well known potential for the interaction between hydrogen molecules[17] $U\rho \approx U_0 \exp(-2\eta\rho)$, $U_0 = 250$ eV, $\eta = 0.85$ a.u., we conclude that the drops are compressed down to

$$\varphi_m \sim 5. \tag{15}$$

After they are stripped from the $\alpha\mu$ ions, the muons are practically instantaneously thermalized in the plasma. Two possibilities then arise: either the muon diffuses toward the drops, or a mesic atom is produced in the plasma and hits a drop. The former case is impossible because the coefficient of diffusion of charged muons in plasma is much lower (by the factor $\sim (m_\mu/m_e)^{1/2}$) than for electrons. Each time an electron hits a drop, it gives up energy $\sim T$ to it. This means that the drops evaporate before they are reached by charged muons. Hence, we conclude that the necessary link in muon catalysis is the formation of mesic atoms in the plasma.

The rate of formation of mesic molecules in drops and of mesic atoms in plasma is high ($\gtrsim 10^9$ s$^{-1}$; Ref. 6), and we shall assume it to be infinite in our approximate estimates. The slowest process is the diffusion of mesic atoms from plasma to drops. Its rate is[6]

$$\lambda_D = 4\pi DrN_d \approx 3\cdot 10^4 rN_d \tilde{T}^{1/2}\varphi_c^{-1}, \tag{16}$$

where $D \approx v_{\rm mes} l_{\rm mes}/3$ and $l_{\rm mes} = (N_c\sigma_{\rm mes})^{-1} \sim 10^{-4}/\varphi_c$ are the diffusion coefficient and mean free path of the mesic atoms in plasma, respectively, $v_{\rm mes}$ (cm/s) is the thermal velocity of the mesic atoms in plasma, $\sigma_{\rm mes} \approx 2\cdot 10^{-19}$ cm$^2$ is the cross section for the scattering of mesic atoms by plasma nuclei, and $N_d$ is the number of drops per cubic centimeter.

The number of cycles is given by

$$X_c \approx (\omega_s + \omega_s^m \lambda_0/\lambda_D)^{-1} w, \tag{17}$$

where $\omega_s^m \approx 0.006$ is the mean muon sticking coefficient of a drop whose radius is given by (6), $\lambda_0 = 0.46\cdot 10^6$ s$^{-1}$ is the rate of muon decay, and $w$ is the muon utilization factor

$$w = 1 - \exp\left[-\left(\lambda_0 + \frac{\omega_s}{\omega^m}\lambda_D\right)\tau_{ev}\right]. \tag{18}$$

According to (7) and (15)–(18), when

$$\omega_s^m \lambda_0/\lambda_D \leqslant 0.2\omega_s \tag{19}$$

we have

$$w \approx 1, \tag{20}$$

$$X_c \approx 1/\omega_s = 300-500. \tag{21}$$

It is clear from (6), (13)–(16), (20), and Fig. 2 that

$$N_d \gtrsim 3\cdot 10^4 \text{ cm}^{-3}. \tag{22}$$

The following is a summary of the necessary plasma parameter values:

$$\begin{gathered} T \sim 100 \text{ eV}, \varphi_c \gtrsim 0.2 \ (N_c \gtrsim 10^{22} \text{ cm}^{-3}), \\ \varphi_m \sim 5,\ r \sim 4\cdot 10^{-3} \text{ cm},\ N_d \gtrsim 3\cdot 10^4 \text{ cm}^{-3}, \\ \omega_d \sim 0.005,\ \omega_m \sim 0.05, \end{gathered} \tag{23}$$

where $w_d = N_d V_d$ is the fraction of volume occupied by the drops, $V_d$ is the drop volume, and $w_m = w_d\varphi_m/\varphi_c$ is the fraction of the material in the form of the drops.

The above conditions can be satisfied in system such as the plasma focus,[19] $\theta$-pinches, or gas liners, i.e., $Z$-pinches (the last possibility was pointed out by R. B. Baksht and A. V. Fedyunin). The sweeping up of material by a moving plasma layer and the strong magnetic field of a pinch (see Sec. 4) play a useful role in such systems from the above point of view (Sec. 4).

## 4. ENERGY BALANCE

Consider pulsed muon catalysis in plasma. The first step is to produce (e.g., in a pinch) the plasma with parameters defined by (23). The energy expended in heating the plasma is given by

$$Q_h = 2N_c TV_{\rm pl} \sim 0.5 V_{\rm pl} \text{ MJ} \tag{24}$$

where $V_{\rm pl}$ is the plasma volume (in cm$^3$). Next, a beam consisting of $n_\mu$ muons and of length $\tau_b \ll \lambda_0^{-1}$ (e.g., $\tau_b \sim 10^{-7}$ s) is introduced into the plasma, and each of these muons produces $X_c$ fusion reactions $d(t,\alpha)n + 17.6$ MeV.

The resulting plasma radiates intensively and the total energy radiated by it during its lifetime under pulsed conditions (the lifetime is $\sim\lambda_D^{-1} \simeq 10^{-7}$ s) is given by

$$Q_h \sim (l_{\rm ph}/d)\sigma T^4 S_{\rm pl}\lambda_D^{-1} \sim 0.01 S_{\rm pl} \text{ MJ} \tag{25}$$

where $l_{\rm ph} \sim 0.01$–$0.001$ cm is the photon mean free path and $S_{\rm pl}$ is the surface area of the plasma (in cm$^2$). In deriving (25), we have taken into account the fact that the plasma radiation is close to blackbody radiation because $l_{\rm ph} \ll d$. The factor $l_{\rm ph}/d$ appears because the plasma does not have a sharp boundary, so that the radiation leaving it is diffuse in character.

The condition for a positive energy balance is

$$n_\mu > \frac{\theta_h + (1-\eta)Q_{\rm rad}}{\eta X_c Q_f - Q_\mu}, \tag{26}$$

where $\eta \simeq 0.35$ is the coefficient of conversion of nuclear energy into useful energy,[20] and $Q_f$ is the nuclear energy yield per muon.

When a uranium blanket is not employed, we have $Q_f = 17.6$ MeV. Consider the case $V_{\rm pl} \sim 1$ cm$^3$ and $S_{\rm pl} \sim 10$ cm$^2$, which corresponds to a pinch of length $\sim 3$ cm and diameter $d \sim 0.5$ cm. From (24) and (25), we find that

$$Q_h \sim 0.5 \text{ MJ},\ Q_{\rm rad} \sim 0.1 \text{ MJ} \tag{27}$$

Hence, and from (26), for the scheme without a blanket

$$X_c \gtrsim 350, \tag{28a}$$

$$n_\mu \gtrsim 10^{18}/\Delta X_c, \quad \Delta X_c = X_c - 350. \tag{28b}$$

In particular, for $X_c = 450$, we have $n_\mu \gtrsim 10^{16}$.

The slowing-down system for negative pions and negative muons with momenta $p \sim mc$ in the small volume (2 cm$^3$) of the $Z$-pinch requires special analysis. For a pinch current $J \gtrsim 1$ MA, the Larmor radius of these particles in the magnetic field of the $Z$-pinch ($\gtrsim 10^6$ G) is small in comparison with the radius of the pinch.

In principle, this solves the problem [this conclusion was established by one of the present authors (L.I.M.) and L. N. Somov]. In view of this, we shall assume that $Q_u \approx 2$ GeV, just as in the case of a molecular $d$–$t$ mixture of large volume.[15,16]

If a uranium blanket is employed, we have $Q_f \approx 500$ MeV (Ref. 20) and the following single condition follows from (26):

$$n_\mu \gtrsim 3 \cdot 10^{16}/X_c. \tag{29}$$

The energy stored in the capacitor bank $Q_{\rm bat} = Q_h + Q_{\rm rad} \approx 0.6$ MJ can be reduced to

$$Q_{\rm bat} \approx Q_h,$$

if, by analogy with thermonuclear fusion, the energy radiated away is replenished by $\alpha$ particles produced in fusion reactions, which slow down in the plasma. Hence, we have the additional (not essential) condition

$$n_\mu \gtrsim 10^{18}/X_c. \tag{30}$$

From (28), (29), and (30), we conclude that, when the blanket is absent, (30) is satisfied automatically, and when the blanket is present, (30) is more stringent than the necessary condition given by (29). Thus, according to (29), the minimum number of muons in the beam for $X_c \sim 300$ is

$$n_\mu \sim 10^{14}. \tag{31}$$

## 5. DISCUSSION OF RESULTS

We have given a detailed analysis of the scheme for muon catalysis in inhomogeneous plasma that was proposed in Ref. 6. In Sec. 2, we calculated the sticking coefficient $\omega_s$ for muons on $\alpha$ particles, taking into account stepwise ionization of the $\alpha\mu$ ions and nonadiabatic effects in reaction (4). In Sec. 3, we found conditions (19) and (23), under which the number of cycles in inhomogeneous plasma can reach $\sim$300–500 [see (21)]. Measurements of $\omega_s$ in plasmas and theoretical calculations of the cross section for reaction (4) near the threshold (probably by the Faddeev method) will be necessary if this result is to be improved.

Several complex problems will have to be solved to implement muon catalysis in inhomogeneous plasma. They include the production of the plasma with the properties defined by (19) and (23).

The next problem will be to produce muon beams of length $\lesssim 10^{-7}$ s, containing $\gtrsim 10^{14}$ muons. It will also be necessary to determine the stopping probability for negative pions and negative muons in the $Z$-pinch (Sec. 4).

We note in conclusion that there are other possibilities for increasing $X_c$, which we have not examined in any detail in the present paper. They involve muon stripping from $\alpha\mu$ ions in $Z$-pinches. This can be done by runaway electrons produced in the strong electric field of the $Z$-pinch.[6]

Stripping can also be produced by fast electrons and nuclei originating in the sausage instabilities of $Z$-pinches.[21] The electron mechanism is probably impractical because it requires a pinch current of $\sim 10^9$ A and duration $\sim 10^{-7}$ s. Stripping by nuclei requires a current of $10^7$ A (the stripping cross section is higher by two orders of magnitude), duration $10^{-7}$ s, and a capacitor bank capable of holding $\sim 5$ MJ.

Much less energy storage is required by another muon stripping mechanism, in which the $\alpha\mu$ ions themselves are accelerated in the sausage instabilities. This requires muon catalysis reactions in a region in which this type of instability is specially produced. The $\alpha\mu$ ions accelerated in the instability up to $\sim$1–3 MeV will lose muons in collisions with nuclei in the pinch plasma with a probability approaching unity.

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