chains in the plastic. When polyethylene films are irradiated, gaseous products are formed, viz: methane, acetylene, and ethylene, which diffuse from the sample within a time that depends on the thickness. In the same paper[3] it was observed that the activity losses may differ in different batches of the same material. It is obvious that this effect can introduce a considerable error in the measured values of the cross sections. We therefore found it advantageous to measure the diffusion losses of C^{11} nuclei in sample of the polyethylene which was used in the particular experiment[1]. Stacks of polyethylene films 0.2 to 20 mg/cm^2 thick and stacks of ethylene copolymer with propylene of equal thickness were irradiated by the internal proton beam of the proton synchrotron at 9 GeV. The films stacked to avoid activity loss due to the recoil nuclei. To determine the percentage loss due to diffusion, a polystyrene sample (plastic scintillator) 95 mg/cm^2 thick, whose diffusion losses do not exceed (0.8 ± 0.1) per cent (according to [2]), was placed in the stack. The number of C^{11} nuclei in the films and in the plastic scintillator was measured by counting the β particles with scintillation counters. A brief description and the parameters of this installation are given in [5]. The main measurement error is due to the uneven thickness of the film. In different exposures, values from 9 to 14 per cent were obtained for the diffusion losses in the polyethylene and in the copolymer of ethylene with propylene. By averaging the data for the diffusion losses from these materials, a value of (11.8 ± 1) per cent was obtained. It was found that the losses depend neither on the radiation intensity nor, in a wide range, on the energy and character of the irradiating particles.

The authors are grateful to M. Shafranov and L. Strunov for help and useful discussions.

[1] Bekker, Kirillova, Nomofilov, Nikitin, Pantuev, Sviridov, Strunov, Khachaturyan, and Shafranova, Intern. Conf. on High-Energy Phys. at CERN, (1962).

[2] Cumming, Poskanzer, and Hudis, Phys. Rev. Lett. **6**, 484 (1961).

[3] H. Fuchs and K. H. Lindenberger, Nucl. Instr. and Methods **7**, 219 (1960).

[4] J. B. Cumming and J. Hudis, Phys. Rev. **128**, 2392 (1962).

[5] Bekker, Pantuev, Sviridov, and Khachaturyan, JETP **45**, 1269 (1963), Soviet Phys. JETP **18**, 872 (1964).

Translated by J. G. Adashko
114

EFFECT OF AN INTENSE LIGHT BEAM ON MATTER AND PARTICLE BEAMS IN A MAGNETIC TRAP

G. A. AKAR'YAN, N. B. DELONE, and M. S. RABINOVICH

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor November 20, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **46**, 814-816 (February, 1964)

In this note we consider possible methods of filling a magnetic trap with fast ions; these are produced either by the disintegration and expansion of dense matter heated and ionized by an intense flash of focused light, or by the effect of an intense light beam on a beam of fast particles injected into a trap.

1. Filling a trap with ions in heating of matter by light in a magnetic field. The heating of ions by electron collisions in the interaction of a focused beam of coherent light with matter is not very effective.[1] To obtain high ion temperatures by this method it is necessary to have high electron temperatures; however, high electron temperatures are difficult to achieve because radiation losses increase with temperature. Moreover, the electron collision frequency decreases with increasing temperature ($\nu \sim T^{-3/2}$) and this leads to a sharp drop both in the absorption of optical energy by the electrons and in the rate of energy transfer from the electrons to the ions. (The transfer time $t \approx M/m\nu \sim T^{3/2}$ becomes greater than the expansion time and the temperatures cannot come to equilibrium with each other.)

We believe that the interaction of light with dense matter in a magnetic trap is more effective because, in the expansion of the plasma that is formed, the plasma pressure causes a direct transfer of energy to the ions, which are confined by the magnetic field of the trap; these ions interact and are thermalized by collision during the time in which they are confined. The strong Coulomb binding of the electron-ion fraction of the bounded plasma provides an effective transfer of energy from the electrons to the ions during expansion even at low densities and low collision frequencies; in particular, this is true in stages of the expansion long after the process has started or at high electron temperatures (low electron-ion collision frequency).

We can estimate the energy of the directed ion motion by making various simplifying assumptions as to the nature of the time variation of the plasma pressure.

If the process is approximately adiabatic (for example, in the case of a single energy pulse and subsequent expansion) the ion energy in expansion is $\epsilon_i \approx kT_{e0}/(\gamma - 1) \sim \epsilon_{e0}$ when $V \gg V_0$, where T_{e0} and V_0 are the initial temperature and volume of the heated region. Thus, even when the ion temperature is much lower than the initial electron temperature (in which case the equalization time $t_1 \sim M_i/\nu_s m_e$ is much longer than the characteristic gas-kinetic expansion time $t_2 \sim a/v \sim 10^{-10}$ sec for $a \sim 10^{-2}$ cm and $v \sim 10^8$ cm/sec) it turns out that after expansion the ion energy is close to the electron energy at the initial temperature.

If the process is approximately isothermal (for example, the case of continuous injection of energy or the case of thermal contact by virtue of the electron thermal conductivity) the kinetic energy of the ions $\epsilon_i \sim kT_{e0} \ln (V/V_0)$. It is evident that when $V \gg V_0$ it is possible to obtain an ion energy several times greater than the thermal energy of the electrons. For example, if the dimensions of the plasma localization region are changed by approximately a factor of ten we find $\epsilon_i \sim 10kT_{e0}$. It is possible to heat the plasma further by induction currents in a rapidly growing magnetic field. If one continues to generate plasma (from the remaining portion of heated matter) as well as heat, the pressure falls off more slowly and the work done on the ions increases.

Because the initial dimensions of the heated region needed for containment of the expanding plasma and effective capture of ions are small, it is possible to use a strong pulsed magnetic field localized in a small volume. If the ion containment time is large enough the ratio of the number of active interactions with containment to the number of interactions in free expansion is

$$\alpha = 1 + n_1 t_1 \langle \sigma v \rangle_{T_{i1}} / (n_0 a/v) \langle \sigma v \rangle_{T_{i0}}.$$

For example, if the ratio of plasma density before and after expansion is $n_0/n_1 \sim 10^6$, the containment time is $t_1 > 10\ \mu$sec, and the gas kinetic expansion time $a/v \sim 10^{-9}$ sec, then with $T_{i1} > T_{i0}$ it is possible that $\alpha \gg 1$ in view of the strong (exponential) dependence of $\langle \sigma v \rangle$ on the ion temperature T_i [2] or on the ion energy if thermalization does not occur.

2. Filling a trap with ions in the interaction of an intense light beam with a beam of fast particles. In order to capture a charged particle injected into a magnetic trap it is necessary to change the mass, velocity, or charge of the particle immediately after it enters the trap. It is convenient to use the strong electric field of an intense coherent light beam for dissociation or ionization of molecular ions or for ionization of neutral atoms injected into a trap.

It has recently been established that a focused beam of coherent light has a strong ionizing effect on a rarefied gas. [3,4] The ionization probability is found to be an exponential function of optical power: $W \sim e^{BP}$, where $B \sim 3 \times 10^{-2}\,\mathrm{kW}^{-1}$. It is evident from this relation that if the optical power is increased moderately one can increase sharply the probability of ionization and provide effective ionization even for fast particles. (For example, with a power of approximately 500 kW it is possible to realize almost 100% ionization of particles moving with velocities of approximately 10^8 cm/sec.)

Excited atoms injected into a trap (at the present time atomic beams have been produced with quantum numbers as high as $n \sim 10$) can be ionized by much smaller light intensities. It should be remembered that the field intensity of a light beam can exceed by many orders of magnitude the motion-generated field intensity ($E = \sqrt{H}/c$ is of the order of several tens of kV/cm) that is used to ionize excited atoms in magnetic traps. [2]

If molecular ions are injected into a trap, capture can occur merely by virtue of the dissociation that takes place in the optical field because of either perturbations of the electron motion or perturbations of the vibrational and rotational states of the nuclei.

Ionization of molecular ions injected into a trap is most effective because in this case the molecular ion dissociates into two ions that remain in the trap.

In certain cases an ion beam can be focused inside the trapping chamber. Using the combination of a focused ion beam and a focused light beam it is possible to increase the time of interaction between the light and the beam up to several milliseconds. The efficiency can also be increased by means of multiple reflections and by reverse reflections of the light back into the trap.

In connection with these problems it is of great theoretical and experimental interest to investigate the ionization and dissociation of molecules and molecular ions in intense optical fields. It is possible that in molecular systems there are various effects that can affect atomic interactions because of perturbations of electron states. For example, polarization can cause repulsion of the atoms or the excitation of vibrational oscillations.[5] A strong optical field can favor exchange transitions and exchange interactions between atoms.

[1] N. G. Basov and O. N. Krokhin, JETP 46, 171 (1964), Soviet Phys. JETP 19, 123 (1964).

[2] L. A. Artsimovich, Upravlyaemye termoyadernye reaktsiĭ (Controlled Thermonuclear Reactions), Fizmatgiz, 1963.

[3] E. Damon and R. Tomlinson, Applied Optics 2, 546 (1963).

[4] F. V. Bunkin and A. M. Prokhorov, JETP 46, 1090 (1964), Soviet Phys. JETP 19, in press.

[5] G. A. Askar'yan, JETP 46, 403 (1964), Soviet Phys. JETP 19, 273 (1964).

Translated by H. Lashinsky
115

DOUBLE CHARGE EXCHANGE OF π^+-MESONS

Yu. A. BATUSOV, S. A. BUNYATOV, V. M. SIDOROV, and V. A. YARBA

Joint Institute for Nuclear Research

Submitted to JETP editor December 4, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) 46, 817-818 (February, 1964)

A large number of stars with secondary π^+ mesons was recorded in a study of the production of mesons by mesons in a nuclear emulsion bombarded by 250—300 MeV π^- mesons[1]. One of the causes of these events is the formation of an additional meson on individual nucleons in complex nuclei, in accordance with the reaction

$$\pi^- + p \rightarrow \pi^+ + \pi^- + n, \qquad (1)$$

in which a secondary negative meson is absorbed in the same nucleus, or else charge exchange in the same nucleus of one of the π^0 mesons from the reaction

$$\pi^- + p \rightarrow \pi^0 + \pi^0 + n. \qquad (2)$$

However, other processes are also possible, and they can result in the formation of a π^0 meson following a collision between a π^- meson and a nucleus. These are double charge exchange processes in accordance with the scheme

$$\begin{array}{l} \pi^- + p \rightarrow \pi^0 + n \\ \qquad\qquad\ \downarrow \\ \qquad\qquad \pi^0 + p \rightarrow \pi^+ + n \end{array} \qquad (3)$$

or

$$\pi^- + (2p) \rightarrow \pi^+ + (2n). \qquad (4)$$

The difficulties in separating the effects from reactions (3) and (4) are apparently the main reason why they have not been investigated. However, an investigation of double charge exchange of mesons is of interest, since this can yield additional information on the interaction between charged and neutral mesons with nucleons in complex nuclei. In addition, great interest is attached at the present time to the possibility of using double charge exchange for the production of new light nuclei[2].

Using the experimental material accumulated in the study of the production of mesons by mesons, it is possible to attempt to separate the hitherto unobserved processes (3) and (4). However, it is necessary to verify first that the secondary π^+ mesons occur also at energies that are considerably lower than the meson production threshold. In this case the π^+ mesons can be produced only in a double charge exchange process, and consequently reactions (3) and (4) can be observed in such an experiment in pure form.

Such an experiment was performed with the synchrotron of the Nuclear Problems Laboratory of the Joint Institute for Nuclear Research. A charge-symmetrical process was investigated. A pellicle stack measuring $10 \times 10 \times 2$ cm was irradiated in an 80-MeV π^+-meson beam. The π^+ mesons were stopped in the emulsion after traveling through 7.5 cm. The irradiation density was 1.2×10^9 mesons per square meter.

The stopped π^- mesons were identified in the developed emulsions by the characteristic σ stars. Prongless stopped mesons were not registered. The tracks of the registered π^- mesons were continued in the stack to the stars produced in the