mation theory, the interaction Hamiltonian is of the form $H = K\sigma$, where K is the transition operator, and σ is the Pauli spin matrix. In addition, the results presented in the last two sections show that the matrix element for the photoproduction of negative mesons on deuterium neutrons close to threshold is independent of the meson momentum. This last conclusion is in agreement with our previous results[1] obtained by a detailed comparison of experiment and the theory of the impulse approximation.

In conclusion, the author expresses his gratitude to Professor V. I. Veksler for his interest and for valuable advice, as well as to A. M. Baldin and V. N. Maikov for participating in discussions of the results.

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OBSERVATIONS OF THE PINCH EFFECT AT DECREASING CURRENTS

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Image-converter photographs have been taken of transient states of pulsed discharges in H_2 and Hg at pressures of 10^{-2} to 10^{-3} mm Hg. The peak pulse currents were 1.3 to 5.5 kiloamperes and the pulses were $300\,\mu$sec long. Electrodynamic deformations (contraction and kinking) are observed at negative values of di/dt. It is found that these deformation effects first disappear (as manifested by the straightening and expansion of the column) at points of high local gas density (anode or cathode, depending on the experimental conditions).

THE contraction of a high-current discharge due to its own magnetic field (pinch effect) has been observed by a number of investigators.[1-5] In some of these investigations, contraction of the column has been observed only at increasing currents.[4]

1. We have carried out a systematic investigation of pinches at increasing and decreasing currents in cylindrical tubes (internal diameter 10 and 32 mm) filled with hydrogen or mercury vapor at pressures of 10^{-2} to 10^{-3} mm Hg. The current pulses were approximately $300\,\mu$sec long with peak values i_p = 1.3 to 5.5 kiloamperes; these currents were obtained by discharging a 300-μf capacitor charged at 1 to 3 kv. Before the experiments the tubes and the electrodes were conditioned by operation at high pulsed currents (5 to 6 kiloamperes) for several hours, either with frequent replacement of the filler gas or with continuous pumping (if Hg vapor was used).

Pictures of the discharge were obtained with an image converter (IC)* operating as a high-speed one-shot shutter. Because of the low intensity, the exposure time could not be reduced below $1.5\,\mu$sec, although special film and exposure procedures were used. Simultaneous oscillograms were taken of the tube current i and the shutter gating pulse V_g, using a two-beam high-voltage oscilloscope. The particular stage of the discharge at which the photograph was taken was determined by the position of the gating pulse with respect to the initiation of current flow in the discharge.

*The tube used in the present work was the PIM-3 image converter developed by M. M. Butslov.

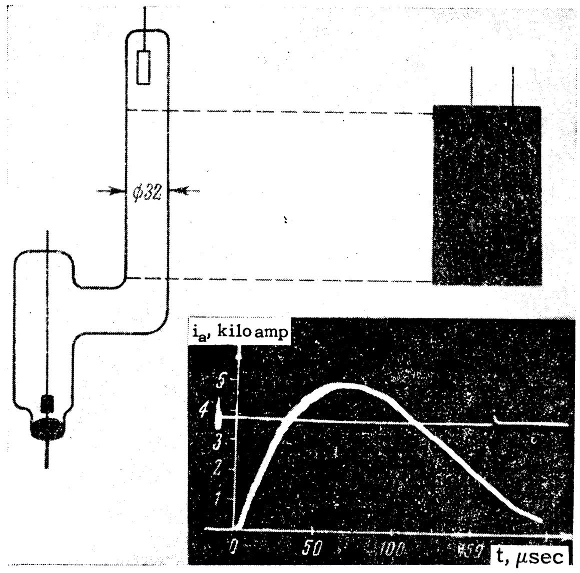

FIG. 1. Photograph of a discharge column in mercury vapor at a pressure $p = 0.3\mu$ Hg. The cooling temperature of the cathode $-15°$C, the exposure is $1.5\,\mu$sec. To the left there is a sketch of the tube, above which are shown the oscillograms for i_p and V_g. The lines above the photograph denote the walls of the tube.

Hereinafter the time between the initiation of current flow and the time at which the photograph is taken will be called the photo-delay time t_{ph} while the discharge current at the time the photograph is taken will be called the photo current i_{ph}.

Many photographs of the discharge were obtained under different current-flow conditions. It is apparent from these photographs that contraction of the column can occur at positive, zero, and negative values of di/dt. As an example, Fig. 1 shows a photograph of a discharge in mercury vapor together with the i and V_g oscillograms for a special tube for which the following parameters apply: working diameter 32 mm, mercury condensation temperature $T_c = -15°$C, peak current $i_p = 5.5$ kiloamperes, photo-delay time $t_{ph} = 160$ μsec (i.e., exposure $80\,\mu$sec after the current reaches its maximum), and photo current $i_{ph} =$ 1.3 kiloamperes. It will be noted that contraction of the column is observed even at long photo-delay times ($t_{ph} > t_p$).

In Fig. 2 are shown two series of photographs of discharges in a narrow hydrogen-filled tube (i.d. 10 mm) with solid electrodes at two pressures, $p = 2\mu$ Hg and $p = 10\mu$ Hg. The peak currents are approximately the same in both series of photographs. The arrows on the current oscillogram below the photographs indicate the time at which the photographs were taken. It is apparent that the discharge remains contracted at negative values of di/dt. On the other hand, an incipient change in the shape of the discharge is observed at the anode: first the kinking disappears and then expansion is observed. The higher the pressure of the filler gas, the greater the fraction of the column in which expansion has occurred at a given photo-delay time. The same effects are observed in a tube of the same diameter filled with mercury vapor. In wider tubes (32 mm), no expansion of the contracted column in the region of the cathode is observed under the same conditions.

In straight tubes 32 mm in diameter, with a liquid mercury cathode which is not separated from the working section of the tube by shields, the straightening and expansion of the contracted

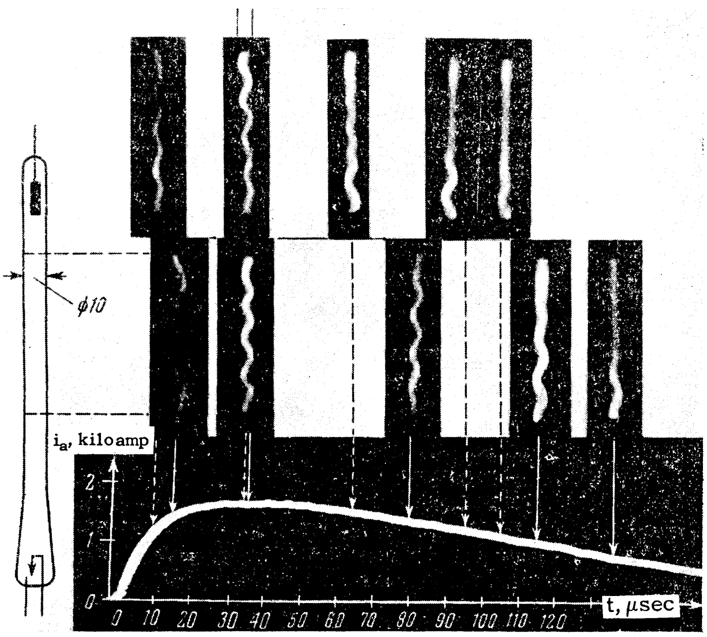

FIG. 2. Instantaneous photograph of the discharge column in hydrogen at $p = 10\,\mu$ HG (upper series) and $p = 2\,\mu$ Hg (lower series). The exposure is $1.5\,\mu$sec. To the left we have a sketch of the tube, above is the current oscillogram; the solid arrows denote the instant of $p = 2\,\mu$ Hg, the dotted arrows denote the instant of exposure at $p = 10\,\mu$ Hg.

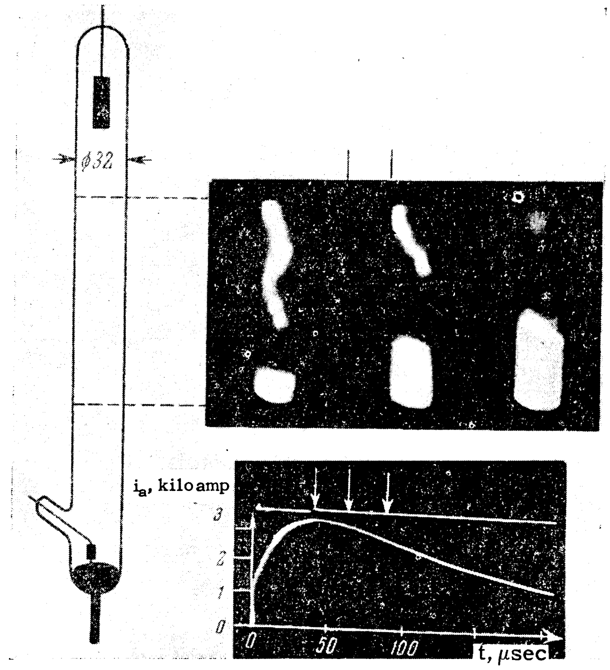

FIG. 3. Instantaneous photographs of the discharge column in mercury vapor at an intial pressure $p = 1\mu$ Hg. The exposure is 1.5 μsec. To the left is a sketch of the tube, above we have the oscillogram; the arrows indicate the time at which the exposure is made.

column starts at the cathode end. This effect is illustrated by the photographs and accompanying oscillograms shown in Fig. 3. These pictures show that longer values of the photo-delay time are to be associated with more uniform illumination of the cathode. However, if the working part of the tube consists of an inclined anode section joined to the cathode part, which is well cooled, (to prevent penetration of the mercury vapor from the cathode into the working part of the tube), no expansion of the column at the cathode is observed in the course of time (cf. Fig. 1). This effect is also absent when solid cathodes are used.

2. It is apparent from the results obtained that the electrodynamic contraction and expansion of the discharge column are not a function of the sign of the current derivative, but only the ratio of instantaneous current to mean gas density in a given section of the tube at a given instant of time. At high currents, a higher gas density (averaged over the cross section) is to be associated with earlier straightening and expansion of the column, i.e., the interval between the time at which the current reaches its peak and the time at which the deformation effects disappear becomes smaller (cf. Figs. 2 and 3). Apparently the pinch vanishes first in the anode region in narrow tubes because this is a point of high gas density. The localized density increase results from the transport of the single type of gas molecules to the anode by virtue of electron collisions; this phenomenon is of greater importance in narrow discharge tubes (cf. for example, reference 6). The expansion of the contracted column at the cathode in tubes with mercury cathodes is explained reasonably by the increase in the vapor density in the cathode region because of evaporation from the cathode. This interpretation is supported by observations made with a bent tube, in which the vapor from the cathode could not reach the working part of the tube; in this case no expansion of the contracted column was observed at the cathode.

These photographs can be used to estimate the velocity of propagation of vapor from the cathode by measuring the distance from the cathode at which expansion of the column occurs on photographs taken at different delay times t_{ph}. In the last column of the table we present data obtained by this means on the velocity of propagation of mercury vapor from the cathode in a tube with an internal diameter of 32 mm at peak currents i_p = 2.8 and 3.2 kiloamperes and an initial pressure $p = 1\mu$ Hg. The data in the table indicate that the displacement velocity of the gas increases with time. This increase is apparently a consequence of the heating of the vapor by the current which passes through it. A rough estimate indicates that the gas temperature reaches values of the order of 10^4 °K.

3. Image-converter observations of discharges in tubes with internal diameters of 10 and 32 mm filled with hydrogen or mercury vapor at a pressure of 10^{-2} to 10^{-3} mm Hg and currents of 1.3 to 5.5 kiloamperes lead to the following conclusions.

(a) The electrodynamic deformations of the mercury column (contraction and kinking) depend on the ratio of the instantaneous current to the mean gas density at a given instant of time and not on the sign of the current derivative.

(b) A changeover from contraction and kinking to expansion and straightening occurs first at points of high local gas density. This changeover

i_a, kiloamp	t_{photos}, μsec	v, cm/sec
2.8	40 55	$4 \cdot 10^4$
2.8	40 70	$12 \cdot 10^4$
3.2	35 42	$2.8 \cdot 10^4$
3.2	35 60	$8 \cdot 10^4$
3.2	42 60	$10 \cdot 10^4$

can occur under the following conditions: (1) in narrow tubes — at the anode, as a consequence of the transport of gas to the anode under the influence of electron collisions; (2) in wide tubes with mercury cathodes — at the cathode, as a consequence of cathode evaporation; (3) in cases of extended contact of the pinch with the walls of the tube — at points of contact, as a consequence of the evolution of absorbed gases from the walls. The last case would seem to explain the effect observed in reference 4.

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PARAMAGNETIC RESONANCE OF FREE RADICALS IN WEAK FIELDS

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The line shape and line width for paramagnetic absorption in crystalline α, α-diphenyl β-picryl hydrazyl (dpph) have been investigated at weak fields at room temperature. It is found that the line shape is Lorentzian near the maximum. An estimate of the half-width is found to be in good agreement with theory.[1] Asymptotic Curie points are computed for a number of new radicals.

1. In the absence of hyperfine-structure splitting, the paramagnetic resonance absorption line shape in weak fields is determined essentially by molecular interactions in the paramagnetic system.

The effect of the dipole-dipole interaction on the absorption line shape has been investigated by Waller,[2] Broer,[3] and Van Vleck.[4] The latter characterized the line shape by its moments. The second moment is affected mainly by the central portion of the absorption curve. Higher moments are affected chiefly by the nature of the absorption curve far from the maximum, where the experimental errors are particularly large. Hence a comparison of the experimental and theoretical values of the higher moments can be made only on a qualitative basis.

The nature of the interaction can be ascertained from the central part of the absorption curve. An equation for the absorption curve in the region of the maximum, which takes into account the magnetic dipole-dipole interaction and the Coulomb exchange interaction, has been obtained by Anderson and Weiss[5] who showed that in the case of a strong exchange interaction the curve has a Lorentzian shape with a half-width given by a phenomenological constant.

A more complete quantum-mechanical analysis of the line shape has been developed by Kubo and Tomita;[1] in this treatment it is shown that the absorbed energy, as a function of frequency in the region of the absorption maximum, is proportional to the Fourier component of the function $G(t)$ if the radio-frequency magnetic field is linearly polarized. Hence the characteristics of the line are