field on, quenching field off, and beam off. The background which is independent of position is seen to be centered at lower energies than the carbon Lyman-α line. It may be due to scattering of x-rays produced when the high-energy carbon beam stops in the Faraday cup.

The proportional-counter Parylene window is 3000 Å thick compared with the 1000-Å-thick Parylene filter used with the Spiraltron multiplier. The background with the proportional counter is about one half that measured with the Spiraltron, possibly because of the greater longer-wavelength absorption of the thicker Parylene. Uncertainties in background are still estimated to contribute ± 5 GHz to the total error.

We have also made detailed measurements of the effects of charge-exchange gas and pressure, and residual gas pressure. Thus far, N_2 and Ar have been used in the adder canal with no effect observed on the quenching decay rate. At higher gas pressures, such that the 4^+ component was 20% of the beam, the background change was minimal. For quenching-region pressures greater than 5×10^{-6} Torr, collisional quenching was observed. All decay curves were obtained at pressures less than 6×10^{-7} Torr. The estimated uncertainty caused by these effects is less than 1 GHz. The total quoted error, 8 GHz, consists of 3 GHz statistical, 5 GHz for background, 2 GHz geometrical, and 5 GHz for all other systematic effects, added in quadrature.

In summary, the new results presented here confirm QED Lamb-shift calculations for $Z=6$ to 1% and indicate that all possible corrections to the assumed nonrelativistic $2P$-state lifetime are less than about 2%. The relatively large cross section for electron pickup to the $2S_{1/2}$ metastable state was crucial to the success of these experiments. Further investigations of this process, both experimental and theoretical, are called for. We are extending the measurements to other adder gases and to hydrogenic oxygen.

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[1]G. W. Erickson, Ann. Phys. (New York) 35, 271 (1965). Recently Erickson has derived a formula for $\mathcal{S}$ in which the Z dependence is factored out in closed form. The theoretical value quoted in this paper is based upon this new expression [G. W. Erickson, Phys. Rev. Lett. 27, 780 (1971)].

[2]M. Leventhal and D. E. Murnick, Phys. Rev. Lett. 25, 1237 (1970).

[3]F. W. Martin, Phys. Rev. 140, A75 (1965). Martin estimates $\sigma(6^+\rightarrow5^+)$ for carbon in argon as $0.23\pi a_0^2$ at 36 MeV. We have assumed $\sigma(6^+\rightarrow5^+)\propto v^{-6}$ as in N. Bohr, Kgl. Dan. Vidensk. Selsk., Mat.-Fys. Medd. 18, No. 8 (1948).

[4]H. Schiff, Can. J. Phys. 32, 393 (1954).

[5]D. W. Marquardt, J. Soc. Ind. Appl. Math. 11, 431 (1963).

[6]H. Kugel, M. Leventhal, and D. Murnick, to be published.

Production of Pulsed Particle Beams by Photodetachment of H⁻†

H. C. Bryant and P. A. Lovoi
Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico 87106

and

Gerald G. Ohlsen
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico 87544
(Received 11 October 1971)

Photodetachment of electrons from an H^- beam by means of a Q-switched Nd laser can produce a pulsed H^0 beam. We have been able to produce 20–40-nsec H^0 pulses with near 100% efficiency. The technique is proposed for selection of single micropulses ($\frac{1}{4}$ nsec) at the Los Alamos Meson Physics Facility for use in a high-resolution time-of-flight system, and is of potential usefulness for other negative-ion accelerators.

Photodetachment of an H^- beam by a laser-produced photon beam, followed by a magnetic deflection of the charged beam, can be used as a means of producing short pulses of protons. Such a technique is of interest in connection with the selection of single micropulses ($\frac{1}{4}$ nsec) at the Los Alamos Meson Physics Facility (LAMPF) in a proposed high-resolution time-of-flight system, as well as for extraction of short and precisely timed pulses from other negative-ion accelera-

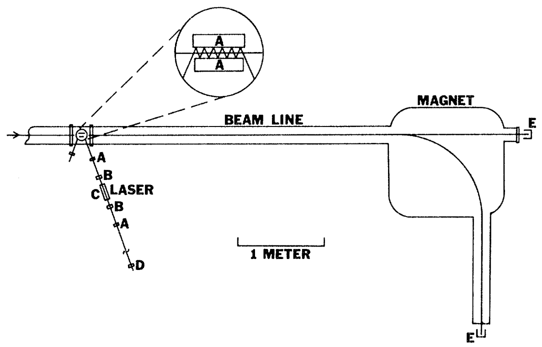

FIG. 1. Schematic of experimental arrangement. *A*, dielectric mirror; *B*, dye cell; *C*, Nd:glass rod; *D*, photodiode; *E*, Faraday cup.

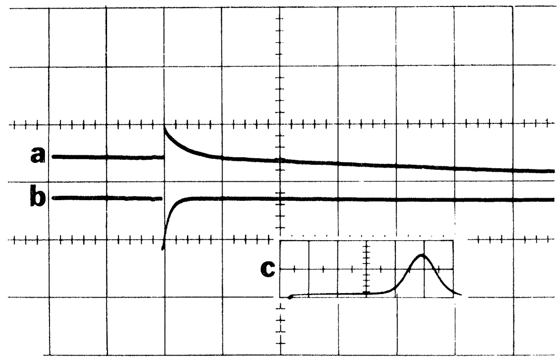

FIG. 2. Oscilloscope traces. (a) Undeflected beam current in Faraday cup (2 V, 100 μsec per large division); (b) integrated photodiode current (0.2 V, 100 μsec); (c) corresponding instantaneous photodiode current (19.8 V, 10 nsec).

tors and storage-ring devices. In the present paper, we discuss an experiment carried out with an external 4-MeV, 4-μA H^- beam ($\beta = 0.092$) from the Los Alamos vertical Van de Graaff accelerator in which it is demonstrated that near 100% detachment can be achieved.

The process of interest is

$$\gamma + H^- \rightarrow H^0 + e^-,$$

which has a threshold at a photon energy of 0.77 ± 0.02 eV,[1] and a broad peak at 1.5 eV; the maximum cross section is about 4.2×10^{-17} cm^2.[2,3] The Doppler effect in cases where the H^- beam velocity is large enables one to vary the effective photon energy from a given laser. Since high-intensity pulses of photons can be produced for very short time intervals, such a detachment method is well within present technology.

A schematic diagram of the experimental ararrangement is shown in Fig. 1. Since the Doppler effect is negligible at this beam energy, the angle of attack is noncritical; however, 70° was chosen since this corresponds to the angle proposed for use at LAMPF ($\beta = 0.841$), where one desires to adjust the effective photon energy to 1.5 eV.

The laser consisted of a water-cooled, 0.78-cm-diam Nd:glass-rod oscillator in an open cavity. The output mirror had a reflectance of 43.5%. A 95% reflectance mirror was used at the opposite end to provide monitoring for the beam. A 5-mm-diam aperture was placed in the laser cavity in order to restrict the output to low-order transverse modes. The spacing between the mirrors was 80 cm. The laser was Q switched using two dye cells (Kodak 9860) within the laser cavity, one on each side of the laser rod. Each Q-switched pulse contained ~50–100 mJ and had a pulse width [full width at half-maximum (FWHM)] of ~20–40 nsec. The "photon target" thickness was increased by eleven reflections at 20° to the normal between the two parallel dielectric mirrors with 1-cm spacing. The diameter of the laser beam entering the detachment cell was 6 mm, and its angular divergence about 2.6 mrad. The laser pulse which emerged through the 95% mirror was monitored by means of a fast vacuum photodiode which had been calibrated against a ballistic calorimeter. The H^- beam was defined by a 5-mm-diam aperture immediately preceding the parallel-mirror assembly. The undeflected neutral beam was detected by an electrostatically suppressed Faraday cup preceded by a 1.13-μm nickel stripping foil. The signal from the Faraday cup was fed into a fast charge-sensitive preamplifier which was a modified version of one normally used with solid-state detectors. The preamplifier sensitivity was such as to produce a 0.72-V pulse for 10^{-13} C of charge delivered within the (several-microsecond) allowable collection time for the preamplifier. The integrated signal from the photodiode (proportional to the laser pulse energy) and the signal from the Faraday cup were photographed simultaneously on a dual-beam oscilloscope (see Fig. 2).

Restricting the data to single Q-switched pulses, we determined the H^0 yield versus total effective laser energy as shown in Fig. 3. Oscilloscope pictures evidencing multiple Q switching (a common occurrence) within times too short to be resolved by the Faraday-cup preamplifier were excluded from the data. It is evident from (1) the saturation in the Faraday-cup signal with increasing laser pulse energy, and (2) compari-

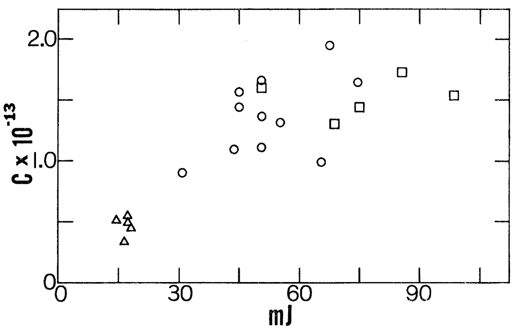

FIG. 3. Detached charge versus effective laser energy. The various symbols correspond to data taken under the following conditions: triangles, return mirror and heat-absorbing glass; squares, return mirror only; and circles, "normal" conditions.

son of the observed charges with that which would correspond to total detachment of the beam [$(1.2 \pm 0.4)\times 10^{-13}$ C for 30 ± 10-nsec segment of a 4-μA H^- beam], that with the larger laser pulses we were detaching essentially all of the beam during the laser pulse interval. We believe the variation in signal heights at a given laser intensity can be attributed to variation in the pulse widths. With the 4-μA H^- beam, a dc background current of about 30 nA was observed at the Faraday cup; this component was presumably produced by collisions with the residual gas and with aperture edges. 60- to 1000-Hz fluctuations in this component necessitated a reduction of the low-frequency gain of the charge preamplifier from values used in standard solid-state detector units.

We were able to make estimates of the FWHM durations of six of the 21 data points shown in Fig. 3 by means of photographs of a Tektronix 519 oscilloscope trace of the instantaneous current in the photodiode, as shown as an insert in Fig. 2. The ratios of instantaneous-to-integrated pulse heights from the photodiode gave us a measure of the effective pulse width. For a triangular pulse, this width would correspond to FWHM. In four cases, where the time scale of the oscilloscope was selected to permit direct measurement of the width of the laser pulses, we found reasonable agreement between the effective and the directly measured values although the latter values were always somewhat lower. This presumably reflects the deviation of the pulse shape (especially in the wings) from triangularity.

The data shown in Fig. 3 were taken under three different conditions. Keeping the laser parameters constant, the points corresponding to the largest pulse energies were taken with a mirror which reflected the laser beam back through the detachment cell, effectively increasing the photon density by a factor of 1.69. The lowest points were taken using the same return mirror with a piece of heat-absorbing glass on the input window to the cell, which transmitted 18.4% of the beam. Finally, the intermediate points were taken under "normal" conditions: no return mirror and no attenuation. For convenience, we have plotted all values as a function of the laser energy which would be required to produce the same photon density under "normal" conditions but with perfect mirrors.

It is of interest to compare the yield of photodetached particles with what one expects from the known cross section, which for the Nd wavelength (1.06 μm) is about 3.9×10^{-17} cm^2. The basic formula for the number of events produced in a colliding beam for which one of the particles is a photon is[4]

$$N = \sigma(1+\beta \cos\alpha)c\int \rho_a \rho_b \, dV\, dT, \tag{1}$$

where σ is the cross section, T the time interval, V the intersection volume, ρ_a and ρ_b the particle densities, βc the velocity of the massive beam, c the speed of light, and α the laboratory angle between the two beams (defined so that $\alpha = 0$ when the collision is head-on). If we assume ρ_a and ρ_b are constants during the interval T and over an interaction volume defined by the intersection of two circular beams of radius R, then the charge released by a laser pulse of N photons crossing an H^- beam of current I is

$$Q = (16\sigma N I/3\pi^2 R c)(1+\beta\cos\alpha)/\beta \sin\alpha. \tag{2}$$

For a 15-mJ laser pulse made to intersect a 4-μA beam 12 times by means of mirrors, and with $R = 0.3$ cm, we estimate

$$Q = 1.06\times 10^{-13}\ \mathrm{C}.$$

Although this is about twice as large as our measured value, as can be seen from Fig. 3, beam inhomogeneities which are certainly present would tend to decrease our prediction, and we feel the agreement is reasonable. (The effect of using a return mirror in getting the data in this region decreases our prediction by only 2.5%) A much more precise knowledge of the spatial and temporal distributions of the laser and H^- beams is necessary in order to use this method for an absolute determination of σ.

We conclude that laser photodetachment is a simple way of producing very short bursts of particles from an H^- beam. For example, by means of an active Q-switch device with a 5-nsec pulse width synchronized with the rf structure, this method should be applicable to the beam at LAMPF for producing solitary pulses. In this case, since the solitary pulses have a natural width of 0.25 nsec, the method is expected to be useful in connection with a high-resolution time-of-flight system. Lasers (using Nd–yttrium-aluminum-garnet amplifiers) having the desired characteristics and firing at a rate of 120 pulses per second are currently feasible.

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[1]D. Feldman, Z. Naturforsch. A 25, 621 (1970).

[2]L. M. Branscomb and S. J. Smith, Phys. Rev. 98, 1028 (1955).

[3]S. J. Smith and D. S. Burch, Phys. Rev. 116, 1125 (1959).

[4]H. Pilkuhn, *The Interaction of Hadrons* (North-Holland, Amsterdam, 1967), p. 28; and an enlightening discussion with J. D. Finley, III.

Differences in Inner-Shell Vacancy Production for Ar-C Collisions in Gas Versus Solid Targets*

R. C. Der, R. J. Fortner, and T. M. Kavanagh
Lawrence Livermore Laboratory, Livermore, California 94550

and

J. D. Garcia
Department of Physics, University of Arizona,† Tucson, Arizona 85717
(Received 4 November 1971)

X-ray spectra are presented for Ar-C collisions in gas and solid (graphite) targets, for collision energies of 80 and 90 keV. In gas targets, with either carbon or argon as the target, inner-shell vacancies are produced essentially only in the argon L shell. For Ar^+ ions incident on graphite, however, there is a high probability of producing vacancies in the K shell of carbon. These observations are plausibly explained within a diabatic molecular-orbitals framework, and lend strong support to such a description.

In this note we discuss some striking differences in the characteristic x rays produced by energetic heavy ions in gaseous as compared to solid targets. We have examined, in this context, the x-ray spectra from low-energy (< 200 keV) Ar-C collisions. For gaseous targets the data indicate that inner-shell vacancies are produced only in the L shell of argon, whereas in argon bombardment of *solid* carbon (graphite) there is a high probability of producing vacancies in the carbon K shell. These differences are qualitatively explained in terms of projectile stripping and the resultant changes in the quasimolecule formed during the collision.

The experimental technique has been described elsewhere.[1,2] A Bragg spectrometer with a lead-stearate film as the diffracting element was used for observing the x rays emitted at 90° to the direction of the incident beam; the detector was a flow-mode proportional counter with an ~2000-Å-thick Parylene window. Gaseous argon and carbon (methane) targets consisted of a gas cell with a small entrance aperture for the beam and a Parylene window for transmitting the x rays; gas pressures were typically maintained at $\sim 5\times 10^{-2}$ Torr. To eliminate effects of Ar^+-Ar collisions due to argon buildup in the graphite target, a clean target spot was used for each data point during these runs; small buildup effects in certain regions of the spectra during the few minutes required to obtain a datum point were removed by using a technique described elsewhere.[3] There was no evidence of argon buildup in the methane target.

Figure 1 shows spectral data for the gas targets. Figure 1(a) is for 90-keV Ar^+ ions incident on methane gas, and also shows the carbon K–x-ray spectrum obtained by 90-keV proton bombardment of the same target. Figure 1(b) is for 80-keV C^+ ions on argon gas, and Fig. 1(c) shows