from the root-mean square of the *observed* experimental distribution. For an individual case, this corresponded to a $\pm 30m_e$ uncertainty for the 743 K^+-mesons, and to $\pm 25m_e$ for the 64 τ^+ mesons. The error in the mean was found by dividing $\pm 30m_e$ by the square root of the number of events of each type.

It is also possible to calculate the absolute values of the masses from the ratio of the mean ranges of the K^+-particles to the mean ranges of the protons. This result will be insensitive to the range-energy relation used, provided the mean ionization potential in emulsion is assumed to be constant in value. In determining this ratio, corrections must be included due to the additional material traversed by particles in passing through the air between the momentum channel and the emulsion stack and also the wrappings on the emulsion stack. This amounted to a $-15m_e$ correction. In addition, a correction of $+2m_e$ is necessary to take into account the difference in projected ranges of the K's and the protons, and a $+8m_e$ correction due to the fact that the beam entered the stack at a slight angle. The result of this determination, using the range-energy relation of Barkas,[3] was $m_K=(965\pm 4)m_e$ and $m_\tau=(969\pm 7)m_e$, where an estimate of the possible systematic error has been included. The difference in mass, however, is as given by Eq. (1)—still $(4\pm 4)m_e$. This result is in good agreement with that of a similar experiment at the Bevatron recently reported at the Pisa Conference.[4]

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Interaction of Antiprotons with Nuclear Fields*

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It has been proposed[1] that saturation of nuclear forces may be explained with the help of a velocity-dependent nuclear potential. The consequences of such a potential can be crudely summarized by stating that within a nucleus the nucleons have an apparent mass which is approximately one-half of the free nucleon mass. In this nonrelativistic theory the nuclear interactions arise from a postulated neutral scalar field.

One of us (H.P.D.)[2] has found a relativistic generalization of the velocity-dependent nuclear interactions. This generalization leads to a remarkably strong attraction between antiprotons (or antineutrons) and nuclei.

The attraction can be obtained in the following heuristic manner. The possible energies of a free proton lie at $\geqq mc^2$ and $\leqq -mc^2$. They are represented by the shaded areas on the left-hand side of Fig. 1. In the interior of a nucleus, the lowest positive energy is depressed by approximately $0.1mc^2$ as shown in the upper right corner of the figure. (It is necessary to

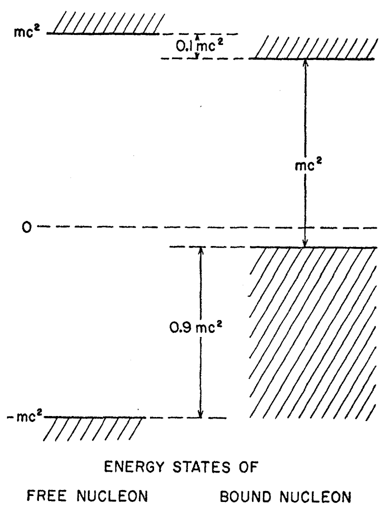

FIG. 1. Energy levels for nucleons and antinucleons.

assume this strong potential to obtain the correct binding of the apparently lighter nucleons.) In order to obtain an effective mass equal to one-half the rest mass, the highest negative energy within the nucleus should lie at a distance $2m_{\mathrm{eff}}c^2=mc^2$ below the lowest positive energy. Thus, as seen in the figure, the lowest negative energy lies $0.9mc^2$ higher for a bound proton than for a free proton. One obtains the energy states of the antiproton from the negative energy states of the proton by inverting the sign. Therefore, an antiproton will find an attractive potential of $0.9mc^2$ within a nucleus. It can be shown that this statement is correct only for an antiproton which is at rest inside the nucleus, and it can be also shown that at higher velocity the attraction is less but of the same order of magnitude.

This result could be experimentally verified by measuring the total collision cross section between antiprotons and nuclei. The cross section should be πr_{eff}^2, where r_{eff} is the nuclear radius plus the range of the nuclear potential. Actually r_{eff} should increase slowly as the kinetic energy of the antiproton becomes small compared to mc^2. Since our nuclear potential is due to mesons of unknown mass, no simple statement on the range of the nuclear potential can be made. Assuming this range to be 10^{-13} cm, one finds that the collision cross section in a poor-geometry experiment is approximately 1.5 times the geometric cross section for a medium heavy nucleus. In no case should the collision cross section be less than the geometric cross section. Since the antiproton is attracted into the nucleus, a considerable fraction of the cross section should correspond to a disintegration process. If an antiproton is not likely to escape from the interior of a nucleus, scattering experiments with antiprotons may give a particularly clear picture of the decrease of the nuclear potential outside the nucleus.

An attraction between a proton and antiproton may lead to the formation of a bound pseudoscalar state which can be identified with the π meson.[3] Since in our view the main part of the nuclear potential is not caused by π mesons, it would be satisfying to follow the reverse procedure and explain the π mesons in terms of the postulated nuclear fields.

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Recoil Broadening of Internal Conversion Lines Associated with Alpha Decay

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The energies of γ rays emitted from nuclei, which have been set in motion by recoil, are altered in virtue of the Doppler shift. Such Doppler shifts have been detected in light nuclei recoiling during nuclear reactions, and have been used to obtain information on the lifetimes of short-lived excited states.[1]

Internal conversion electrons emitted from recoiling nuclei may exhibit a significant broadening in the conversion line, as a simple consequence of addition of velocities. Such effects are entirely negligible in β decay, but are appreciable for recoil nuclei associated with alpha decay. If the conversion electron is emitted at an angle θ with respect to the direction of recoils, then the momentum p of the electrons is given by the relation,

$$p=p_0[1+(v_\alpha/v_\beta)\cos\theta],$$

where p_0 is the momentum of the electron emitted by a stationary nucleus, v_α is the velocity of the recoiling nucleus at the time of emission, and v_β is the velocity of the conversion electron. Assuming, for simplicity, that there is no angular correlation between the alpha particles and the conversion electrons, then for an ideally thin source situated in vacuum on an ideally thin backing, the momentum distribution will be a triangle with a base $2\Delta p$ equal to $2(v_\alpha/v_\beta)p_0$, and with a relative half-width $\Delta p/p$ equal to v_α/v_β. The relative half-width of the corresponding energy or momentum distribution obtaining with the unconverted γ rays, because of the Doppler shift, is v_α/c, where c is the velocity of light. For low energies the recoil broadening of the conversion lines will be considerably greater than the Doppler broadening of the unconverted γ rays.

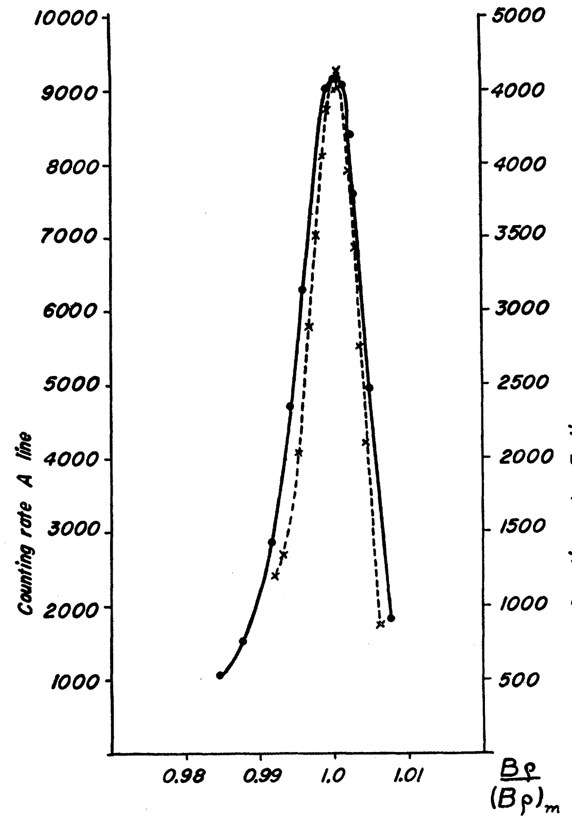

Fig. 1. Comparison of the line shapes of the "A" line and "F" line from thorium active deposits, using a resolution of 0.8%. The momentum distributions are plotted as a function of $B\rho/(B\rho)_m$, where $(B\rho)_m$ is the peak momentum, in order to facilitate comparison. The full curve corresponds to the "A" line (ordinate scale on left). The broken curve corresponds to the "F" line (ordinate scale on right). The half-width of the "F" line is 0.8%. The half-width of the "A" line is 1.0%.

Line broadening and shifts arising from α recoil have been observed for the L_1 conversion electrons of the 40-kev transition in ThC″ (Tl^{208})—the "A" line from thorium active deposit. The energy of the conversion electron is 24.5 kev corresponding to a velocity v_β of 9×10^9 cm/sec; the energy of the α particle leading to the 40-kev level is 6.04 Mev, leading to a recoil velocity v_α of 3.3×10^7 cm/sec. The relative momentum half-width for an ideal source should thus be 0.36%. Figure 1 shows a comparison of the widths of the thorium "F" line (148 kev) and "A" line obtained from the same source (a ThB source prepared by recoil on 0.17 mg/cm² aluminum and in equilibrium with its products) using a short-lens spectrometer at a resolution of 0.8%. Since the conversion electrons giving rise to the F line follow β decay, no detectable recoil broadening should be present.