EXPERIMENTS TO MEASURE THE FORCE OF GRAVITY ON POSITRONS

William M. Fairbank
Department of Physics
Stanford University
Stanford CA 94305
USA
Fred C. Wittebom
NASA Ames Research Center N245-6
Moffet Field
USA

Presented by
William M. Fairbank

Abstract

An experiment is described to measure the force of gravity on positrons. The experiment is a modification of a previous experiment used to measure the force of gravity on electrons. Recent techniques for thermalizing positrons by reflection from copper surfaces make such an experiment feasible. Such an experiment could in principle check for a scalar fifth force coupling to leptons.

For many years we have been involved in the measurement of the force of gravity on electrons with the ultimate objective of measuring the force of gravity on positrons(1-4) The experiments on positrons assumed increased importance with the suggestion of Nieto, Goldman and Hughes including the talk at this conference by Hughes that antimatter would behave differently to a scalar and a vector force than ordinary matter, the vector force being attractive for antimatter interacting with ordinary matter but repulsive for ordinary matter interacting with ordinary matter. They have stimulated present efforts to measure the force of gravity on antiprotons(6). A measurement on the positron as well as the antiproton would differentiate between forces on leptons and on baryons. It now appears possible to make a slow positron source sufficiently well thermalized to make the experiment we performed on electrons possible for positrons(7-9).

Figure 1 shows the apparatus used to measure the force of gravity on electrons. It consists of a pulsed electron source, two copper cylindrical drift tubes each 1 meter long and 2 inches in diameter, placed in a 4 inch diameter copper tube. This 4 inch tube serves as a vacuum jacket and the alignment fixture for a high homogeneity vertical superconducting solenoid. Pulses of electrons emitted from the bottom traverse the axis of the drift tube guided by the magnetic field and their time of flight is determined with the aid of an electron multiplier detector at the top of the second drift tube.

Two methods have been used to measure the forces on the electrons. In one method the second drift tube is electrically removed from the time of flight by applying a small positive voltage and the time of flight is measured as a function of various axial electric fields applied by running a current axially along the walls of the lower drift tube. A variety of techniques are employed to eliminate non uniformities in the axial electric and magnetic fields. These are described elsewhere(1-4). A very important technique involves the use of ground state electrons in which only electrons are employed which are in the magnetic ground state making the vertical magnetic force on the electrons smaller than the gravitational force on the electrons. The results of this method for electrons are shown in figure 2 and 3. In figure 2 the time of flight distributions for three different electric fields applied along the drift tube are shown. Figure 3 summarizes the results of a series of experiments which showed the reduced force determined from a variety of applied fields plotted against the applied field(1-2). From these data it was determined that there was no force on the electron to within ±10% of mg for an electron to within one standard deviation. This was interpreted to mean that free electrons had the same gravitational mass as electrons on the surface of the drift tube. Indeed the success of the first experiment in which the patch effect field was shielded at low temperatures is still a theoretical puzzle(10-

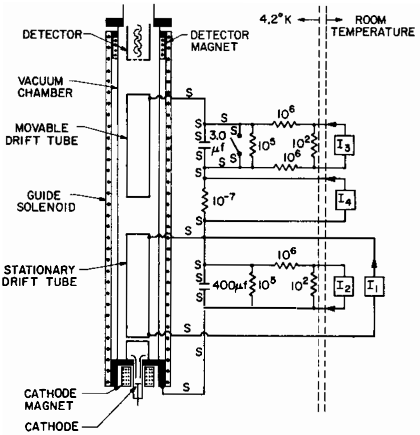

Fig. 1 Schematic diagram of the free fall apparatus for electrons. The regulated current supply I_1 maintains both drift tubes at a negative voltage relative to the vacuum chamber. I_2 controls the relative potential of the two drift tubes. In the first experiment the movable drift tube was positively biased so that electrons moved slowly only in the stationary tube. The current I_3 produces a uniform electric field in the stationary tube.

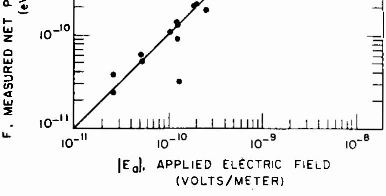

Fig. 3. Measured force versus applied force. The vertical value is the force determined from analysis of the time of flight distribution curves. The horizontal value is the absolute magnitude of the deliberately applied electric field. The solid diagonal line represents $F=|eE_a|$ for a particle having the electron's inertial mass.

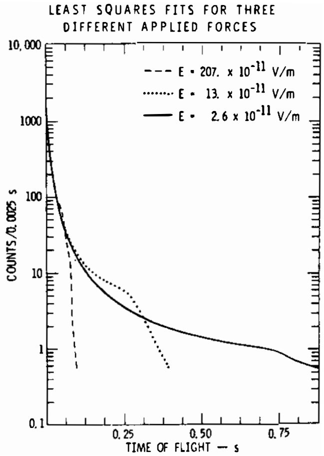

Fig. 2. N'(t) vs TOF for three different applied forces.

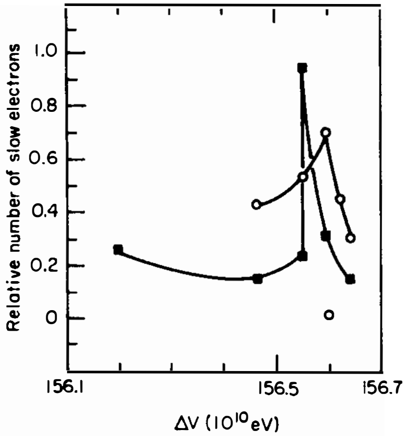

Fig 4. Data from movable drift tube experiments. The horizontal axis is the applied potential difference between the movable and stationary drift tubes. The vertical axis is the ratio of the number of electrons with flight time between 25 and 50 ms to the number with flight times between 12.5 and 25 ms. Each ratio requires 10 to 15 h of data accumulation. O, Separation = 1 cm; ■, separation = 31 cm.

12) John Bardeen(13) and John Madey(14) have each suggested that a surface state of electrons produce the shielding.

The second method(1-2) does not depend on the fortuitous shielding of a patch field. In the second method the potentials of the two drift tubes are adjusted until they are precisely equal. This equality is determined by repeatedly performing time of flight experiments as a function of the potential applied to the second drift tube until the fraction of slow moving electrons is maximized. Figure 4 shows the results in an experiment for the drift tubes of figure 1 using electrons. By determining the equality for two different heights for the second drift tube, the difference in potential due to the height between the two drift tubes can be determined.

In the electron experiment the gravitational potential difference mgh is cancelled by the gravitationally induced electric potential from the electrons on the walls. For positrons this electric field would exert a force in the opposite direction. Therefore in pure gravity one would measure 0 for the electrons and mgh for the for the positrons. If in addition there is a scalar or vector fifth and sixth force on the electron, we measure for the positron twice the sum of the gravitational force mg and the scalar force. The vector force cancels out. If we calibrate the electric field by measuring the force of gravity on the proton we can determine also the vector force if we know the total forces on the proton.

It is now possible to obtain slow positrons by reflection from a metallic surface(7-9). The fact that the positron work function is repulsive enables one to retrieve the thermalized positrons before they are annihilated in the metallic surface. They would then be measured in an experiment similar to that which was done for electrons.

Such an experiment for positrons is shown in figure 5. A pulsed beam of positrons created with aid of an electron accelerator and thermalized with a spread of about 1 volt, are reaccelerated to about 1 kilovolt and caused to impinge on a single crystal copper surface in a high vacuum. The positrons penetrate a short distance into the metal and are thermalized. Since the work function for a metal is negative for a positive particle, the positrons , when they are thermalized are reflected out of the metal. A few percent of the positrons escape annihilation in the metal and are thermalized to the temperature of the metal. If the copper surface is in a high magnetic field, say 50 kilogauss, then most of the reflected positrons will be in the magnetic ground state. These thermalized positrons are then guided down the axes of the apparatus with a guide magnetic field until they reach the upper of three drift tubes. Since the positrons arrive at this drift tube in a short time pulse it is possible to use the drift tube as a velocity selector, the fastest positrons arriving at the end of the drift tube first. If a retarding voltage which varies with time is applied between the first and 2nd drift tubes the spread in energy of the positrons can be further reduced.

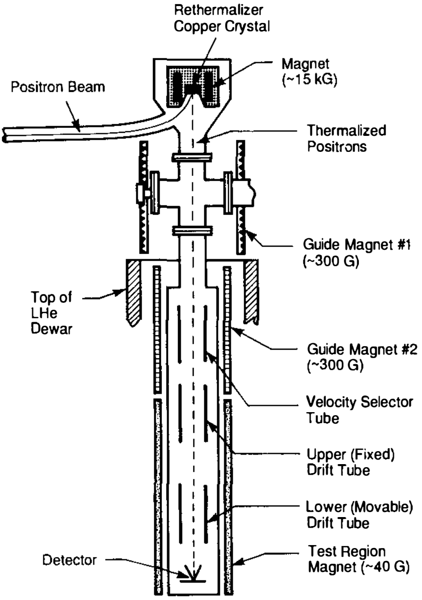

Fig. 5 Schematic diagram of the apparatus for measuring the force of gravity on positrons.

Using one of these two methods one has at the entrance to the second drift tube a distribution of slow positrons mostly in the magnetic ground state that contains some very slow positrons, in sufficient numbers to perform the experiment to determine the force of gravity on individual positrons. At this point the positrons would be introduced to the 2nd drift tube and simultaneously to a very much smaller magnetic field. This reduces the magnetic energy for all electrons except those in the magnetic ground state. Since energy is conserved for the positrons all positrons except those in the magnetic ground state are accelerated arriving at the other end of the lower drift tubes in a time short compared with one millisecond. Only the ground state positrons remain.

In a series of pulses the arrival times of the very slow positrons are determined After measurements for enough time to determine the distribution of slow positrons the voltage between the lower two drift tubes is changed. As a function of the voltage between the two drift tubes the number of slow positrons arriving per unit time is determined. From our experience with electrons(1-2) this should peak with a spread in the peak of a small percentage of the force of gravity on the electron. The space between the drift tubes is then changed and the voltage of maximum time of flight again determined. If there is a gravitational plus fifth force acting on the positron the energy with which a positron arrives at the second drift tube will change, causing the maximum in slow positrons to occur at a slightly different balancing voltage. From this we can in principle determining the change in potential energy of the positron in going through a height h between the drift tubes. The distance between the two drift tubes can be measured very accurately to determine the force of gravity on positrons to the highest possible accuracy.

If one is to determine the strength of a fifth or sixth force on positrons or antiprotons it will be necessary to make extremely accurate measurements since it is not expected that the correction for the fifth or sixth force on positrons and antiprotons will be very large. Still this may be the only way that one can uniquely determine the force on the electron and the proton and will represent the first measurement of gravity on antimatter. The antiproton has the advantage that the conventional force of gravity on the antiproton is 2000 times larger than on the positron and is therefor in many ways easier to measure. However, if the fifth force is equal on the positron and the antiproton, then as a percent of gravity, the positron is 2000 times easier to measure. If the fifth force turns out to have the short range it seems to have, then it would be possible to perform the positron and antiproton experiments with the drift tube horizontal near a large mountain since the guide magnetic field will be very little affected by gravity.

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