## *Muon and Electron Magnetic-Moment Anomalies Disagree with Theory*

New determinations of $g-2$, the anomalous magnetic moment, for the muon and electron show small departures from their theoretically predicted values. The muon value, reported by Francis Farley (Royal Military College of Science, Shrivenham, UK) at the Washington APS meeting, is higher than theory. The electron value is lower, according to Arthur Rich of the University of Michigan who recently recalculated (*Phys. Rev. Letters* **20,** 967, 1968) $g-2$ using the data of David T. Wilkinson and H. Richard Crane (*Phys. Rev.* **130,** 852, 1963). New experiments to measure the electron g-factor anomaly are being done by Rich and by Larry Knight of Stanford University and by G. Gräff at the Physics Institute of the University, Bonn.

So far the only observed difference between a muon and an electron is that the muon is 207 times heavier. Because the muon is heavier than the electron, it is more sensitive to any possible violation of quantum electrodynamics that might occur at sufficiently high energy (or small distance).

**The muon results** are from the latest in a series of experiments done at CERN with a 5-meter-diameter muon storage ring (PHYSICS TODAY, March 1967, page 81). The CERN group, besides Farley, consists of John Bailey, Walter Bartl, Robin Brown, Hans Jostlein, Emilio Picasso, Bob Williams and Gregor von Bochmann.

Three separate runs including both positive and negative muons give consistently higher results than the value predicted by quantum electro-dynamics, which is $(g-2)/2 = (11656 \pm 1) \times 10^{-7}$. Farley reported that the experiment gives $(g-2)/2 = (11666.3 \pm 3.1) \times 10^{-7}$; the discrepancy is $+(880 \pm 270)$ parts per million. He emphasized that this is an *interim result: the group is continuing* its measurements, looking for systematic errors that could account for the discrepancy. We understand, however, that later runs tend to confirm the quoted value.

$g-2$ measures the interaction of the magnetic moment with its own electromagnetic field. In the usual picture the muon or electron is surrounded by a cloud of virtual photons that modify its properties. Theorists have frequently speculated that the muon may also emit another photon-like particle, which also has spin 1, but has a large mass $M$ (a few times the proton mass). This proposed new field would have its own reaction on the muon and would in its turn affect the value for the muon magnetic moment. If the muon $g$-2 results are correct, the implication for a vector field of mass $M$ and coupling constant $f$ is $f^2/M^2 \approx (34 \text{ GeV})^{-2}$. This field is just one possible explanation.

**Electrons.** Measurement of $g-2$ for the electron is much more precise than that for the muon, since it is easier to obtain lots of electrons. In calculating the theoretical value for $g-2$, one uses a power series in $\alpha$, the fine-structure constant. Since electron experiments are much more sensitive to a change in $\alpha$ than the muon experiments, one has a tough time deciding which is the best value of $\alpha$ to use.

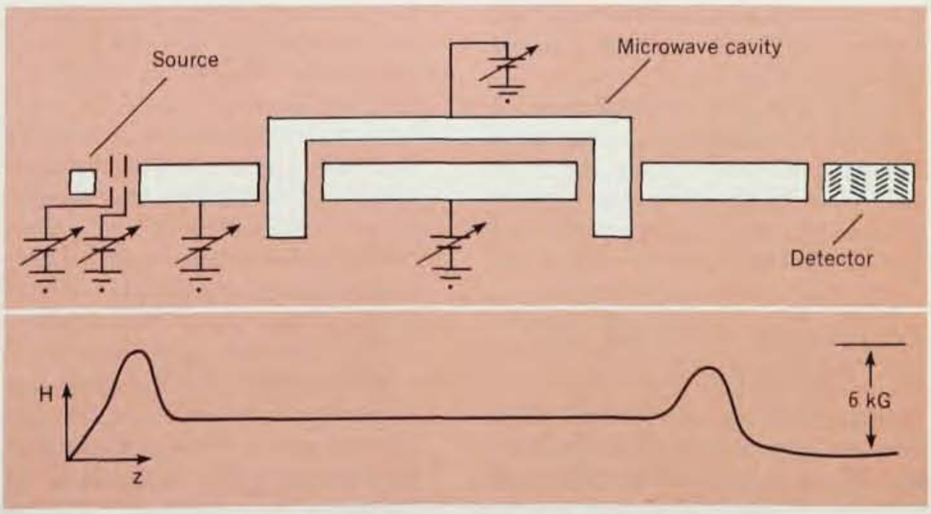
One can find $\alpha$ from the Lamb-shift fine-structure splitting in deuterium, from muonium hyperfine structure, hyperfine splitting in hydrogen, or the ac Josephson effect in superconductors (PHYSICS TODAY, April 1967, page 66). Until recently the fine-structure measurements disagreed with the Josephson value. Now new fine-structure measurements at Yale and at Brown University (reported by Sidney Drell of Stanford at the international Atomic Physics Meeting at New York University in June) yield values for $\alpha$ that agree with the Josephson value.

In Rich's calculation, if one uses the value found from the Josephson effect, theory predicts $(g-2)/2 = (11596.41 \pm 0.03) \times 10^{-7}$. Using the Wilkinson and Crane data, Rich calculates an experimental value of $(g-2)/2 = (11595.57 \pm 0.30) \times 10^{-7}$.

New experiments on $g-2$ are obviously in order. The CERN group plans to continue refining its experiments and hopes to improve its muon measurements by a factor of ten. Electron measurements are under way at Michigan and Stanford.

**At Stanford** Larry Knight, Brian Kincaid and William Fairbank are measuring $g-2$ of the free electron by a cyclotron and spin-resonance experiment on very slow electrons. They believe the experiment is capable of an accuracy of 1 part in $10^8$ and will certainly be accurate to 1 part in $10^6$. In an earlier experiment (Knight's Stanford PhD thesis) he measured the anomaly $a = (g-2)/2$ to 30% by varying the force on ground-state electrons with a magnetic field and studying the change in distribution.

The group makes very slow electrons with the technique used by Fred Witteborn and William Fairbank to measure the gravitational force on freely




**APPARATUS TO MEASURE ELECTRON g-FACTOR ANOMALY. Ground-state electrons are separated from those in other states and move through the microwave cavity. The detector measures the number of electrons as a function of their cyclotron resonance frequency and their spin resonance frequency to yield g-2 value.**

falling electrons (PHYSICS TODAY, July, page 71). The electron beam, produced in 0.1-millisec pulses, is surrounded by a 6-kG field (see figure). Then the electrons move adiabatically to a lower magnetic field. They are all accelerated in the direction of the field, except for the ground-state electrons, which gain magnetic energy and slow down. This slowing down offers a way to separate in time the ground state from all other states.

Now a microwave cavity is placed in the beam with a magnetic mirror between cavity and detector. By observing the number of slow electrons that reach the detector as a function of frequency the cyclotron resonance $f_c = 2\mu_0 B/h$ ($\mu_0$ is the Bohr magneton) and the spin resonance $f_s = 2(1 + a)\mu_0 B/h$ can be detected. If $B$ is constant than $a = (f_s - f_c)/f_c$; so in principle the magnetic-moment anomaly can be read directly off a counter.

**At Michigan** Rich, together with Crane and John Wesley, are refining the Crane experiment to measure $g - 2$ to a few parts per million. The technique, used by Crane and several collaborators over the last 17 years to get increasingly better values for $g - 2$, uses Mott scattering to partially polarize and analyze a high-energy beam of electrons. The beam is scattered by a gold-foil polarizer; a slit system selects only those electrons coming off at right angles with the field. These drift down-field in a tight helix (pitch less than 0.2 deg) and are trapped between two magnetic mirrors, where their magnetic moments precess. After a predetermined time, the electron bunch is ejected from the trap and scattered by a second gold foil that acts as an analyzer.

By studying the number of electrons scattered from the analyzer as a function of time spent in the trap, one can determine the difference between the cyclotron and spin frequencies and thus determine $g - 2$. —GBL

### *Balloon-Borne Telescope Sees An X-Ray Flare in Sco X-1*

An unexpected and very intense x-ray flare has been detected from the x-ray star Sco X-1 in the constellation of Scorpio. Walter H. G. Lewin, George W. Clark and William B. Smith of MIT reported the experiment in *The Astrophysical Journal* **152**, L55, 1968.

Although small optical flares have been seen from x-ray sources, no one has previously seen x-ray flares. However, some variations (by a factor of as much as ten or so) in x-ray intensity have been seen from observations made several months apart.

The MIT group used a balloon-borne telescope to survey the southern sky. Intensity during the early part of the flight was consistent with previous measurements. But half an hour before the flight was terminated, the equipment found a sudden fourfold increase in 20–30-keV x rays. The peak was reached in less than 10 min and then decreased in the next 20 min.

### *400-MeV Electron Linac to Have High Intensity, Long Duty Cycle*

MIT is building a 400-MeV electron linear accelerator, which at full energy is expected to produce 100–200 microamperes with a 1.8% duty ratio. At 100 MeV, beam intensity should be about three times as high with a duty ratio of about 6%. The pulse length of the machine can be varied from a few nanoseconds to 15 microseconds, and the repetition rate will be adjustable to a maximum of 5000 Hz.

The klystrons being developed for the accelerator are expected to have an average power capability of 75 kW and peak power capability of 4 MW.

Among the tools to be used with the new accelerator is a special "energy-loss" spectrometer that will provide very-high-resolution (approaching 1 part in $10^4$) beams at almost full intensity, according to Peter Demos, director of the MIT Laboratory for Nuclear Science.

### *Second No Longer Ephemeral: Cesium Transition Instead*

Last fall the 13th General Conference on Weights and Measures defined the second as "the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the fundamental state of the atom of cesium 133." The atomic definition was deliberately chosen to make it indistinguishable from the "ephemeris second" (adopted in 1956), which was a fraction of the tropical year at 1200 hours, ephemeris time, 0 Jan. 1900 and was based on the apparent motion of the sun across the celestial sphere.

### *High-Flying Telescope Seeks Improved Photo Resolution*

Princeton astronomers are flying a telescope above 95% of the earth's atmosphere to achieve photographic resolution of planetary markings and galactic structure unattainable at the bottom of the ocean of air.

Known as Stratoscope II, the 3500-kg telescope system is carried to an

## IN BRIEF

The first 13 in a series of 44 geologic maps of the visible surface of the moon have been published by the US Geological Survey. An index map is available from the Survey's distribution centers in Arlington, Va., and Denver.

1.5-meter sections of a 2200-meter Antarctic ice core are available to qualified investigators from the National Science Foundation. These and samples of contained volcanic ash, cosmic particulates, etc., can be obtained from the Chief Scientist, NSF Office of Antarctic Programs.

The National Bureau of Standards and the National Research Council Office of Critical Tables are coöperating to improve data available to nuclear-magnetic-resonance spectroscopists. Standards makers are scrutinizing selected molecules to determine current accuracy limits and compiling high-precision tables of chemical shifts and coupling constants.

A 2.1-meter hydrogen bubble chamber began running at SLAC last March. The stainless-steel chamber was rebuilt from the old 72-inch chamber at Lawrence Radiation Laboratory. It is the second chamber to be cycled at SLAC; the first is a 1.1-meter hydrogen chamber.

Two Emperors (tandem van de Graaff accelerators) are going to France, one to the Center for Nuclear Research at Strasbourg and the other to the University of Paris laboratory in Orsay. And the Center for Nuclear Research in Saclay is converting its standard tandem model to a King, which will produce 15-MeV protons.

Another King is being tested in the Nuclear Structure Laboratory at the State University of New York at Stony Brook.