## *Pair-Production Experiment Finds QED Still Good Theory*

Despite two separate experiments in the past two years on electron-positron pair production that indicate a violation of quantum electrodynamics for small distances (about $3 \times 10^{-14}$ cm), a recent experiment at the DESY 6.2-GeV electron synchrotron does not confirm the earlier results. A collaboration between groups from the Deutsches Elektronen-Synchrotron, Hamburg (J. G. Asbury, W. K. Bertram, U. Becker, P. Joos, M. Rhodes and A. J. S. Smith) and Columbia University (S. Friedlander, C. Jordan and Samuel C. C. Ting) reports (*Phys. Rev. Letters*, 9 Jan. 1967) that first-order quantum electrodynamics correctly predicts pair production for momentum transfers as great as 400 MeV/*c*.

The best evidence for the present theory of quantum electrodynamics comes from precise measurements of energy levels of simple atoms and of the anomalous part of the electron or muon magnetic moment. Only the muon magnetic moment, however, checks the theory at very small distances (high energies); experiments at CERN over the past four years indicate that quantum electrodynamics holds over distances that are as small as $10^{-14}$ cm.

Although the obvious experiment is to hit atomic electrons with a beam of electrons, the energy available is not great enough to provide sufficient sensitivity to observe any breakdown in theory. One solution is to use colliding beams. In a Stanford experiment reported last June (by W. Carlisle Barber, Bernard Gittelman, Gerald O'Neill and Burton Richter) 300-MeV electrons struck 300-MeV electrons; no disagreement with quantum electrodynamics was found.

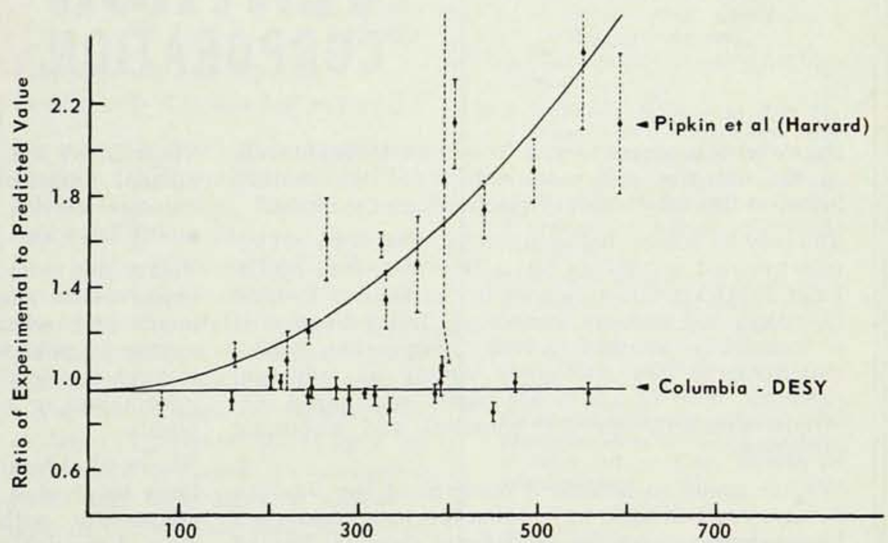
**Look at pairs.** Another way is to look at electron-positron pairs formed when gamma rays strike a target. Most pairs come off at small angles, corresponding to small four-momentum transfers, but some will emerge at large angles, say several degrees. One can just look at the pairs that come out at equal angles $\theta$ and thus minimize the unwanted effects of nuclear structure. The test of quantum electrodynamics improves with larger transverse momentum $p\theta$, where $p$ is the momentum of electron or positron.

The first wide-angle pair-production experiment, reported in April 1965 by a Harvard group at the 6-GeV Cambridge Electron Accelerator (Ralph Blumenthal, D. C. Ehn, William Faissler, Peter Joseph, Louis Lanzerotti, Francis Pipkin and D. G. Stairs), did find a violation. Pipkin and his collaborators compared their cross sections for wide-angle pair production with those predicted by the Bethe-Heitler formula (modified by J. D. Bjorken, Sidney Drell and Steven Frautschi to account for the nuclear form factor and recoil effects) for momentum transfers as great as 400 MeV/*c*. With increasing gamma energy the Pipkin group found increasing deviation between observed and predicted cross sections.

Early last year a group at the Cornell 2-GeV electron synchrotron (Eric Eisenhandler, J. Feigenbaum, Nariman Mistry, D. Rust, Albert Silverman, Charles Sinclair and Richard Talman) did a similar experiment, but limited by their lower accelerator energy, they could only measure cross sections up to 100 MeV/*c*. In this region they too found some deviation between theory and experiment.

A third experimental check, on photoproduction of muon pairs, also indicated a small deviation from theory, but the deviation was much smaller, and its sign was the opposite of Pipkin's. It is not clear, however, that quantum electrodynamics should be the same for both muons and electrons. The muon experiment, also done with the CEA, was reported last October by J. K. dePagter, Jerome Friedman, George Glass, R. C. Chase, Marvin Gettner, E. von Goeler, Roy Weinstein and Adam Boyarski.

**Columbia-DESY results,** first discussed at the Berkeley high-energy physics conference in September by Ting, are in disagreement with the recent electron-positron pair-production experiment. The DESY experiment, done at the 6.2-GeV electron synchrotron, used a symmetrical magnetic spectrometer and counter techniques to detect the pairs. The figure compares the Pipkin and Columbia-DESY results. The Columbia-DESY physicists note in their paper that the accuracy with which they can compare experimental yield with theoretical




**NUMBER OF ELECTRON-POSITRON PAIRS observed at CEA and DESY is compared to value predicted by quantum electrodynamics.**

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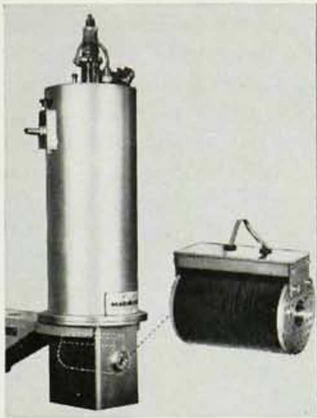

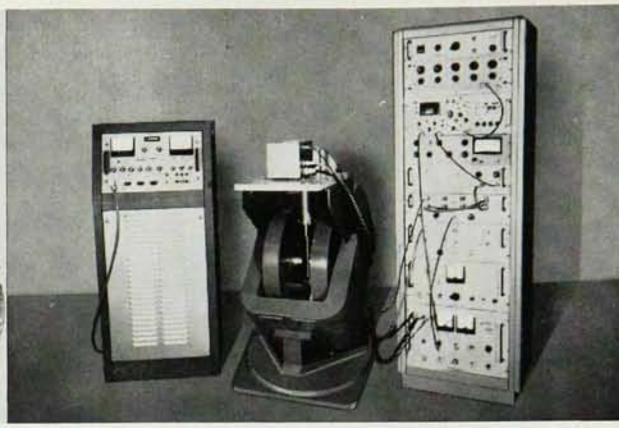

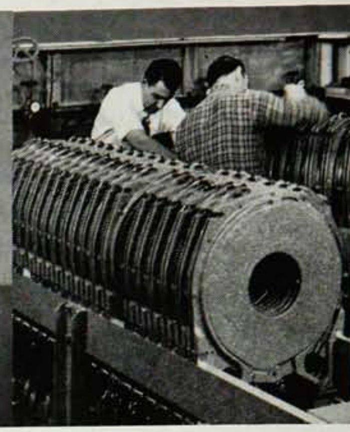

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predictions is limited to a few percent by uncertainty in the contribution of Compton processes and lack of precise measurement of inelastic form factors of the target nucleus.

Meanwhile Pipkin is repeating his electron-positron pair-production experiment at the CEA and hopes to have his data analyzed by the end of the summer. He also plans to do a similar experiment with the 18–20 GeV beam at the Stanford Linear Accelerator later this year. And at Cornell, Talman has repeated his experiment at slightly higher momentum transfers. —GBL

### *Tunneling Electrons Cause Molecular Vibrations*

In the 28 Nov. *Phys. Rev. Letters* Robert Jaklevic and John Lambe of the Ford Scientific Laboratory report changes in the conductance of tunnel diodes caused by the excitation of molecular vibrations in impurities at the diode junction. This effect may be useful as a probe of the detailed surface structure of junction interfaces. Possibly it also will be useful in tunnel-diode technology.

Jaklevic and Lambe observed that the conductance of a clean junction of aluminum, oxide and lead rises anomalously at bias voltages corresponding to the energies of O–H vibrational modes. Although the surface was clean, there could have been water in the oxide or adsorbed on the interface that would give rise to the anomalies.

When the surfaces were contaminated by exposure to air, propionic acid or acetic acid, anomalies occurred at bias voltages corresponding to the characteristic organic C–H vibrational modes as well. Other metal-oxide-metal junctions exhibit similar behavior.

Confirmation that the anomalies are caused by such molecular vibrations comes from work subsequent to their Letter. Jaklevic and Lambe contaminated the surfaces with deuterated compounds and found that the anomalies then occurred at bias voltages shifted by an amount appropriate for the vibrational modes of deuterated molecules.

Structure in the conductance was also observed at bias voltages below 100 mV where excitation of the oxide molecules is expected. Thus, although no definite identification of the structure was possible, it may be that the junction itself can be involved in the effect as well as impurities.

Other anomalies also have been observed in the conductance of tunnel diodes. Adrian Wyatt found that many metal-oxide-metal junctions have about 10% greater conductance at zero bias than at 5 mV. Ralph Logan and John Rowell observed these peaks and also peaks in the zero bias conductance of p-n junctions.

Explanations of such anomalies depend upon detailed properties of the junction surface. For example, Joel Appelbaum showed that the zero-bias anomaly could arise from second-order scattering by localized states near the barrier. As Philip Anderson has suggested, such states could be impurities or interstitial metal atoms in the oxide.

Clearly a sensitive probe of surface properties and impurities would be valuable for investigating such detailed surface structure. It would also be useful for studying other surface phenomena such as surface conductivity, adsorption and catalysis. If the tunneling scattering process can be related to the more general problem of surface scattering, electron excitation of molecular vibrations in tunnel diodes may serve as a microscopic probe of surface phenomena.

### *Fantastically Low Energy Accelerator Reaches 100 peV*

Reversing the trend in accelerator construction, William Fairbank and his collaborators (Fred Witteborn and Larry Knight) at Stanford University have built a Fantastically Low Energy Accelerator, also known as FLEA. The device is being used to compare gravitational attraction of the electron and positron and to measure their anomalous magnetic moments. Ground state electrons or positrons travel up a cylindrical tube, guided by a magnetic field, and their time of arrival is measured. Fairbank, speaking at the annual Belfer Graduate School conference on 16 Nov., said that in a 2-cm-diameter tube they have obtained