

INTRODUCTORY REMARKS ABOUT GREGORY BREIT

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On behalf of the Yale Physics Department I am glad to welcome you and happy so many are able to attend the Gregory Breit Centennial Symposium. President Levin will be with us at about 10:30 am and will make his welcoming remarks then. He apologizes that he is unable to be here at the opening of our Symposium.

This symposium has been organized by a committee of the Yale Physics Department consisting of R. Adair, Y. Alhassid, T. Appelquist, C. Baltay, D. Allen Bromley, R. Casten, J. Harris, P. Hohenberg, V.W. Hughes (Co-chairman) and F. Iachello (Co-chairman).

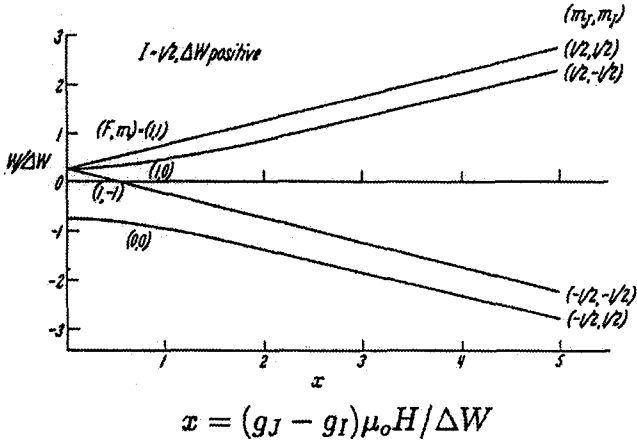
The initial stimulus for this Symposium came as an apparently innocent question I was asked one evening about 8 months ago at Brookhaven National Laboratory. Andrzej Czarnecki, a young particle theorist at BNL, who has among other things calculated the higher order electroweak contribution to the muon $g-2$ value and also the positronium lifetime, had been reading papers by Breit on atomic hyperfine structure and quantum electrodynamics. Andrzej asked if I knew when Breit was born. I didn't happen to know, and he said 1899. This had an immediate implication, especially in this year of the American Physical Society Centennial celebration. We checked the 1899 date by the following day – there was some concern whether it might have been 1898. The National Academy of Sciences biographical memoir by Mac Hull settled the question. I am happy to say that Andrzej will be at our symposium. Although I hadn't known the year Gregory was born, I knew the day in the year-- namely July 14, French Bastille Day. Those of you who knew Gregory will understand that the symbolism of this day is not what one would easily associate with Gregory Breit.

Gregory Breit was on the faculty of the Yale Physics Department as the Donner Professor of Physics from 1947 to 1968, when he retired.

The first day of our Symposium, entitled *The Legacy of Gregory Breit*, emphasizes the recent status of topics to which Gregory Breit made major, seminal contributions. These include quantum electrodynamics and atomic physics and several topics in nuclear physics, notably the isotope shift, the nucleon-nucleon interaction and heavy ion collisions. The topic of supersymmetry in nuclei is distantly related to Breit's research on isospin symmetry of neutron and proton forces. A highlight of the first day is the talk by John Wheeler, who spent a year as a postdoctoral fellow with Breit, on "One Hundred Years of the Quantum: The Glory and the Shame." The second day of our symposium, entitled "Frontiers of Nuclear Physics," covers forefront and futuristic topics in nuclear physics.

Breit-Rabi Energy Level Diagram for Hydrogen Ground State

$$[\mathcal{H} = a\vec{I} \cdot \vec{J} + \mu_0 g_J \vec{J} \cdot \vec{H} + \mu_0 g_I \vec{I} \cdot \vec{H}]$$



Transition Frequencies

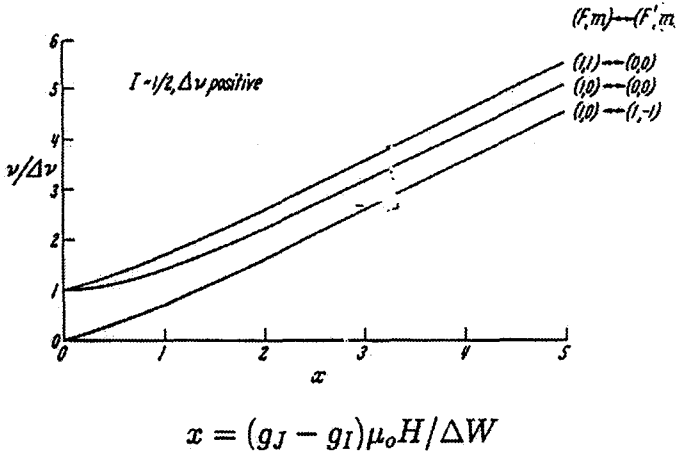


Figure 1. The Breit-Rabi energy level diagram and its consequences, taken from "Measurement of Nuclear Spin", G. Breit and I.I. Rabi, *Phys. Rev.* **38**, 2028 (1931).

There are several central and well-known topics in physics to which Breit's name is solidly attached. The important Breit-Rabi formula (Figure 1) for the energy levels of a hydrogen atom in its ground state as a function of magnetic field was developed at the time Breit was at New York University and Rabi was at Columbia. Rabi was building up his atomic and molecular beams laboratory and the interest was in nuclear spins and moments. The Breit-Rabi equation and its extensions to other atoms has been a cornerstone for precision atomic spectroscopy.

The electron-electron or Breit interaction (Figure 2) was developed by Breit based on the quantum electrodynamics field theory of the early 1930's. A principal application is to the fine structure of helium in its 2^3P_J states. Gerry Brown will discuss the Breit interaction from a theoretical point of view and Massimo Inguscio will describe the current status of measurement of *He* fine structure by laser spectroscopy.

Breit (Electron-Electron) Interaction

$$B = -\frac{e^2}{2r_{12}} \left[\alpha_1 \cdot \alpha_2 + \frac{(\alpha_1 \cdot r_{12})(\alpha_2 \cdot r_{12})}{r_{12}^2} \right]$$

For *He*(1s 2p, 3P_J)

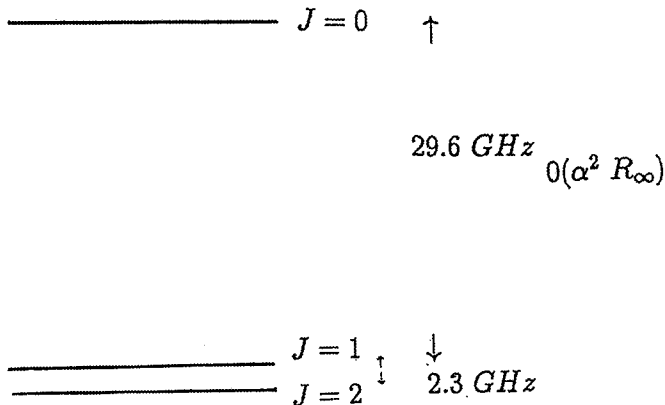
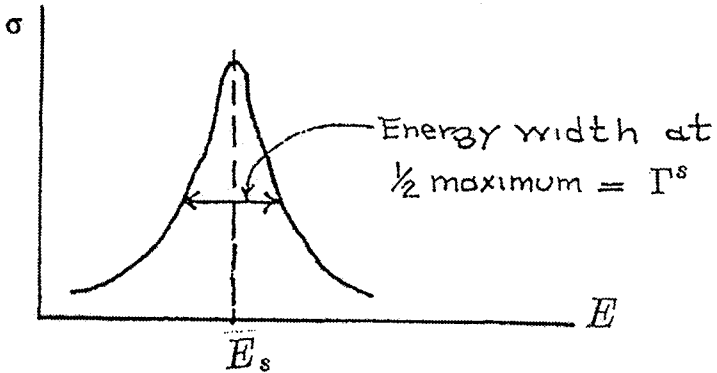


Figure 2. The Breit electron-electron interaction and its consequences in helium, taken from, "The Effect of Retardation on the Interaction of Two Electrons", G. Breit, *Phys. Rev.* **34**, 817 (1929), "Fine Structure of Helium as a Test of the Spin Interaction of Two Electrons", G. Breit, *Phys. Rev.* **36**, 383 (1930), "Dirac's Equation and the Spin-Spin Interaction of Two Electrons", G. Breit, *Phys. Rev.* **39**, 616 (1932).

Breit-Wigner Formula

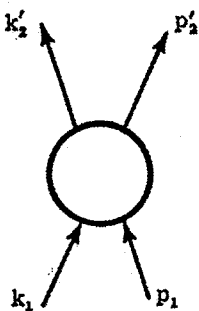


$$\sigma(\alpha, \beta) = (2l + 1) \pi \lambda_{\alpha}^2 \frac{\Gamma_{\alpha}^s \Gamma_{\beta}^s}{(E - E_s)^2 + (\frac{1}{2}\Gamma^s)^2}$$

Figure 3. The Breit-Wigner Formula, taken from "Capture of Slow Neutrons", G. Breit and E. Wigner, *Phys. Rev.* **49**, 519 (1936),

The Breit-Wigner resonance formula (Figure 3) was derived to understand the capture of slow neutrons by a heavy nucleus. An intermediate short-lived compound state is produced whose lifetime determines the width of the resonance in the capture cross section as a function of neutron energy. The Breit-Wigner formula has been a cornerstone of nuclear reaction theory.

Breit Frame of Reference



$$\mathbf{k}_1 + \mathbf{k}_2' = 0$$

$$\mathbf{k}_1 = (\omega, \mathbf{k})$$

$$\mathbf{k}_2' = (\omega, -\mathbf{k})$$

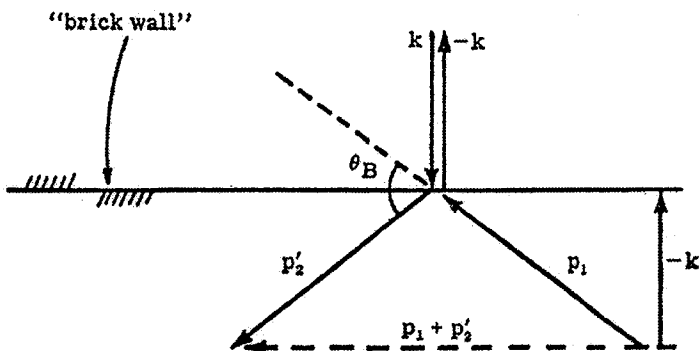


Figure 4. The Breit frame.

In addition to the laboratory and center of mass frames of reference, the Breit frame of reference (Figure 4) is often convenient to use in treating scattering problems. It was developed in Breit's studies of proton-proton scattering.

Breit made a major contribution to the discovery of the electron anomalous magnetic moment as indicated in Table 1. The measurement of the hfs interval in hydrogen provided the first discrepancy with a prediction of the quantum

electrodynamics theory of the mid-1940s. Hence it was the first evidence of a radiative correction to QED, later understood within the renormalized theory of QED. Breit made the first suggestion that this discrepancy of $\Delta\nu$ (expt) with the Fermi theory might be due to an anomalous magnetic moment of the electron. He calculated this electron anomalous magnetic moment with the developing renormalized QED theory, but his calculation contained an error which Schwinger pointed out in his own correct calculation.

Some brief information about Breit's bibliography is given in Table 2. Breit's early training was in electrical engineering, as indicated in the first few references. His work with Tuve on propagation of radio waves was pioneering. Breit and Tuve also developed a high voltage electrostatic generator of 1 MeV for nuclear reaction studies. Early in his career Breit became interested in basic fundamental problems such as space quantization and the properties of a spinning electron.

We shall hear in this symposium of many other researches by Breit. They are included in his bibliography of some 330 papers, published over a period of 53 years. Breit wrote several major review articles, one on quantum theory of dispersion and another on the nucleon-nucleon interaction.

Despite all his accomplishments and active leadership in many fields of physics, Breit was basically a modest man. Professor Rabi told the following story. In 1939, the annual meeting of the National Academy of Sciences was held in April in Washington, DC and shortly thereafter the annual meeting of the American Physical Society took place in Washington at the Shoreham Hotel. At that National Academy meeting Breit was elected to be a member of NAS and was immediately told that he was elected. Then at the APS meeting the next day Rabi saw Breit sitting on a couch in the Shoreham Hotel, looking very sad and despondent. Rabi asked Breit, "Why do you look so sad? You have just received the honor of being elected to the Academy." Gregory replied: "But there are so many more worthy candidates." Rabi answered: "Don't worry, Gregory. You and I know it but nobody else does." The next year, 1940, Rabi was elected to the Academy.

Table 1.

Breit and the Electron Anomalous Magnetic Moment.

H hfs

H hfs measurement at Columbia in disagreement with theoretical value from Fermi formula by ~ 0.002 .

$$\Delta\nu \text{ (expt.)} = 1\,420.410(6) \text{ MHz}$$

$$\Delta\nu \text{ (theor.)} = 1\,416.97(54) \text{ MHz}$$

“The hyperfine structure of atomic hydrogen and deuterium.”

J.E. Nafe, E.E. Nelson, and I.I. Rabi, *Phys. Rev.* **71**, 914 (1947); J.E. Nafe and E.E. Nelson, *Phys. Rev.* **73**, 718 (1948).

H Lamb Shift

“Fine structure of the hydrogen atom by a microwave method.”

W.E. Lamb, Jr. and R.C. Rutherford, *Phys. Rev.* **72**, 241 (1947).

Suggestion that electron has an anomalous magnetic moment

“Does the electron have an intrinsic magnetic moment?”

G. Breit, *Phys. Rev.* **72**, 984 (1947).

Measurement of the electron anomalous magnetic moment

“The magnetic moment of the electron.”

P. Kusch and H.M. Foley, *Phys. Rev.* **72**, 1256 (1947); *Phys. Rev.* **73**, 412 (1948).

Theory

“On quantum-electrodynamics and the magnetic moment of the electron.”

J. Schwinger, *Phys. Rev.* **73**, 416L (1948).

Erratum: “Does the electron have an intrinsic magnetic moment?”

G. Breit, *Phys. Rev.* **73**, 1410 (1948).

“Some effects of the intrinsic magnetic moment of the electron.”

G. Breit, *Phys. Rev.* **74**, 656 (1948).

“The effect of nuclear motion on the hyperfine structure of hydrogen.”

G. Breit and R.E. Meyerott, *Phys. Rev.* **72**, 1023 (1947).

G. Breit, G.E. Brown and G.B. Arfken, *Phys. Rev.* **76**, 1299 (1949).

Table 2.

Early Publications

The calculation of detecting and amplifying properties of an electron tube from its static characteristics. *Phys. Rev.* **16**:387 (1920).

The propagation of fan shaped group of waves in a dispersing medium. *Phil. Mag.* **44**:1149 (1922).

The field radiated from two horizontal coils. *Bureau of Standards Scientific Paper* No. 431 (1922).

With P. Ehrenfest. A remarkable case of quantization. *Zeit. Physik* **9**:207 (1922), *Proc. Amsterdam Acad.* **25**:2 (1923).

The Heisenberg theory of the anomalous Zeeman effect. *Nature* **112**:396 (1923).

Note on the width of spectral lines due to collisions and quantum theory. *Proc. Nat. Acad. Sci.* **9**:244 (1923).

The electromagnetic mass and momentum of a spinning electron. *Proc. Nat. Acad. Sci.* **12**:451 (1926).

With M.A. Tuve. Radio evidence of the existence of the Kennelly-Heaviside layer. *J. Wash. Acad. Sci.* **16**:98 (1926).

With M.A. Tuve and O. Dahl. Effective heights of the Kennelly-Heaviside layer. *Proc. Inst. Radio Eng.* **16**:1236 (1928).

The magnetic moment of the electron. *Nature* **122**:649 (1928).

Quantum theory of dispersion. Parts I-V. *Rev. Mod. Phys.* **4**:504 (1932).

Quantum theory of dispersion. Parts VI-VII. *Rev. Mod. Phys.* **5**:91 (1933).

Some 330 papers

On quantum theory, atomic physics, (hfs, fine structure), nuclear physics, (nuclear moments, isotope shift, nuclear forces, nuclear reactions, heavy ions), particle physics, (nucleon-nucleon interaction)

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Final Paper

With M. Tischler, S. Mukherje and G. Pappas. Magnetic-moment effects on tests of charge independence in nucleon-nucleon scattering. Proc. Nat. Acad. Sci. USA 70: 2178 (1973).