**Modern Trends in Basic and Applied Laser Spectroscopy**

**Lund 6-7 April, 2010**

# Once upon a time

# there was no laser …

**How Science changed the course of World History**

**How World History changed the course of Science**

**Ingvar Lindgren: After-dinner speech**

**Isaac Rabi (1898-1988)**

**Inventor of ABMR – first radio-frequency-resonance method 1937**

**Nobel Prize 1944**

MARCH 15, 1939 PHYSICAL REVIEW VOLUME 55

# The Molecular Beam Resonance Method for Measuring Nuclear Magnetic Moments

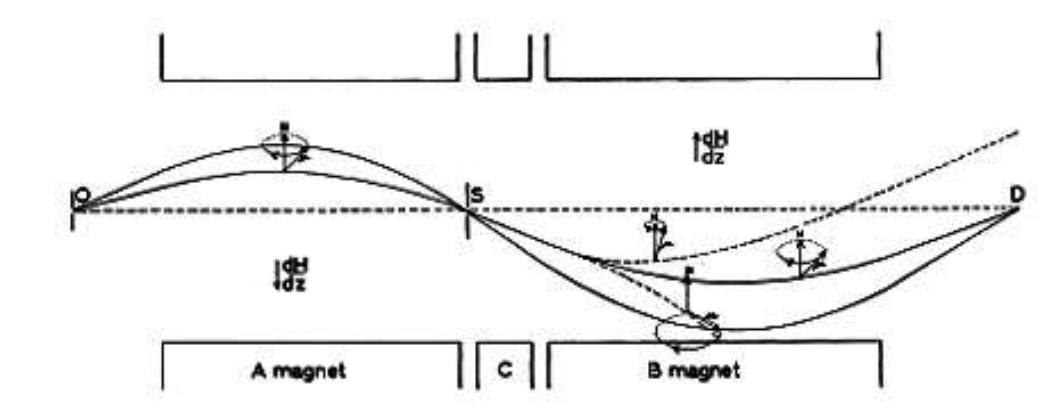
## The Magnetic Moments of $_3Li^6$, $_3Li^7$ and $_9F^{19}$

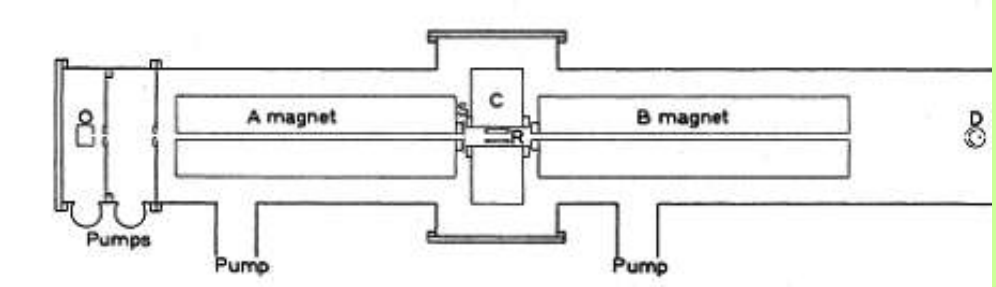
I. I. RABI, S. MILLMAN, P. KUSCH, *Columbia University, New York, New York*

AND

J. R. ZACHARIAS, *Hunter College, New York, New York*

(Received January 20, 1939)



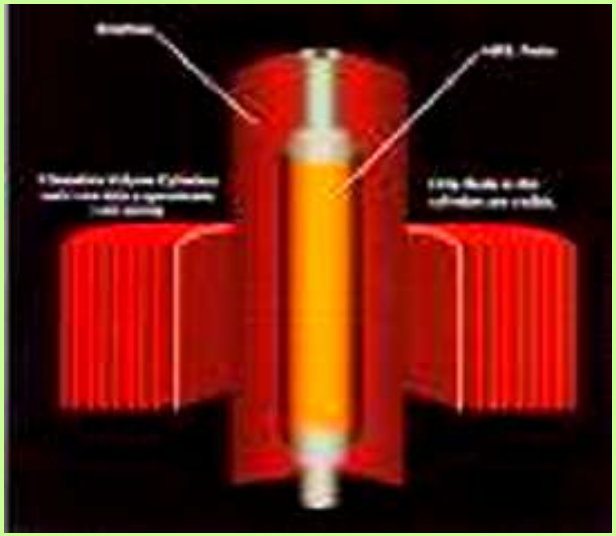

**Radio-frequency induced transitions**

**The demonstration of induced transitions by Rabi represents the start of a new epoch in physics**

**New resonance metods followed rapidly**

# Nuclear Magnetic Resonance NMR

## discovered 1945



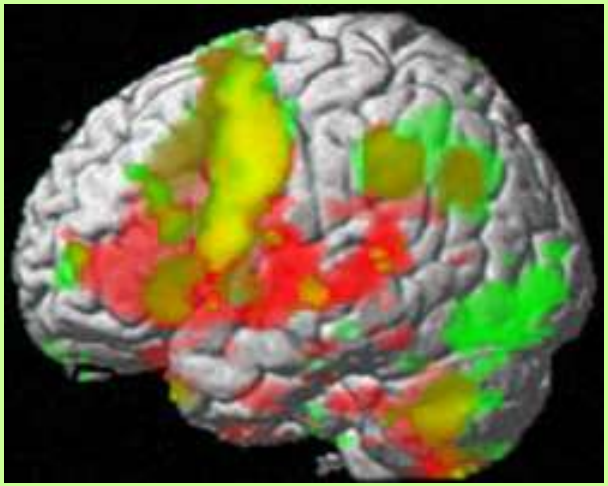
**Felix Bloch** 1905-1983

**Edward Purcell** 1912-1997

## Nobel Prize 1952

"for their development of new methods for nuclear magnetic precision measurements and discoveries in connection therewith"

# ~~Nuclear~~ Magnetic Resonance Imaging MRI



# Electron Spin (Paramagnetic) Resonance  ESR/EPR

**Discovered in 1944 by E.K. Zavoisky, USSR, and B. Bleaney, Oxford**

# Separate oscillatory fields 1949

## A New Molecular Beam Resonance Method*

NORMAN F. RAMSEY
*Harvard University, Cambridge, Massachusetts*

August 22, 1949

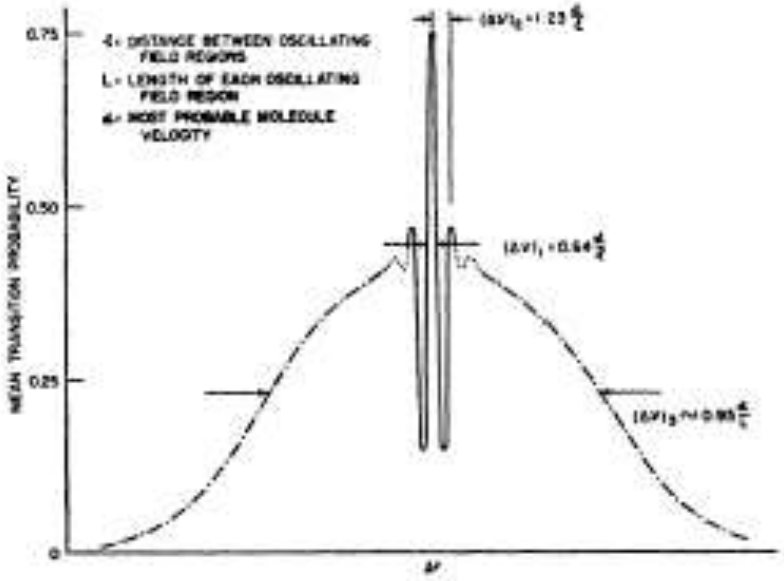
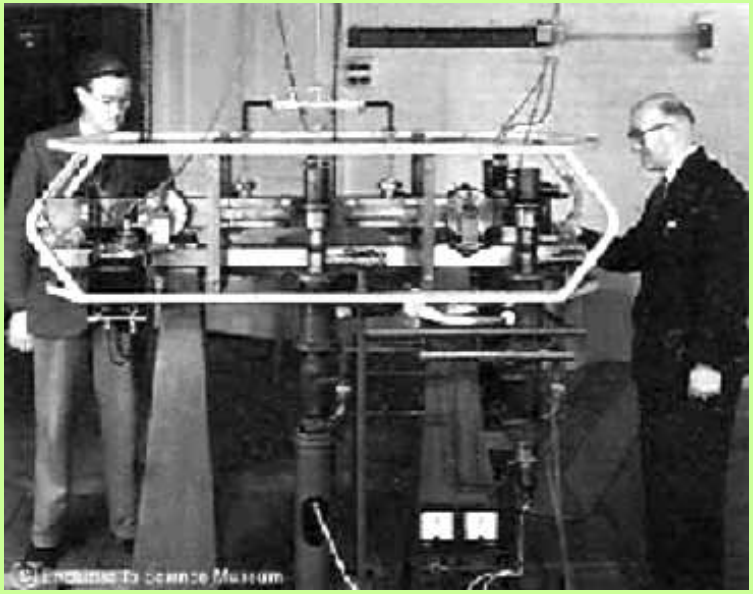
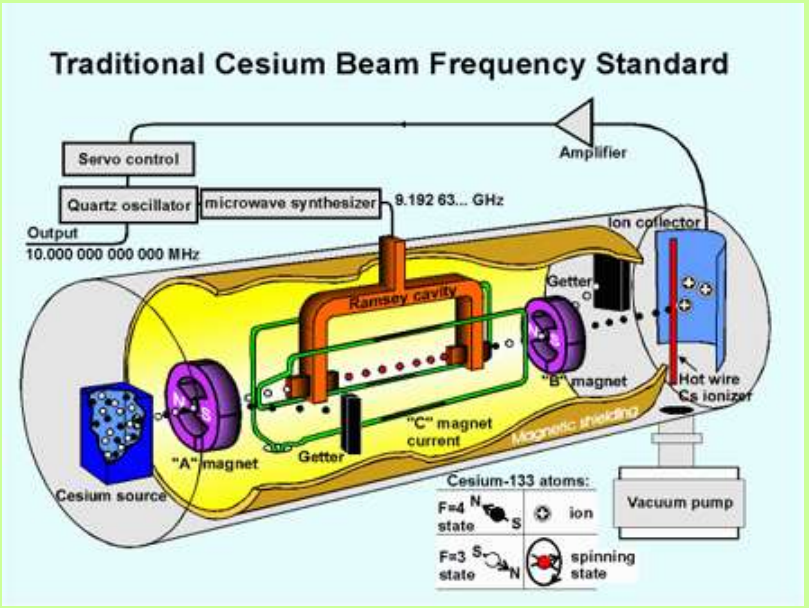



FIG. 2. Transition probability showing effect of finite length of oscillating field regions.

**Led to the caesium clock and new def. of time 1967**

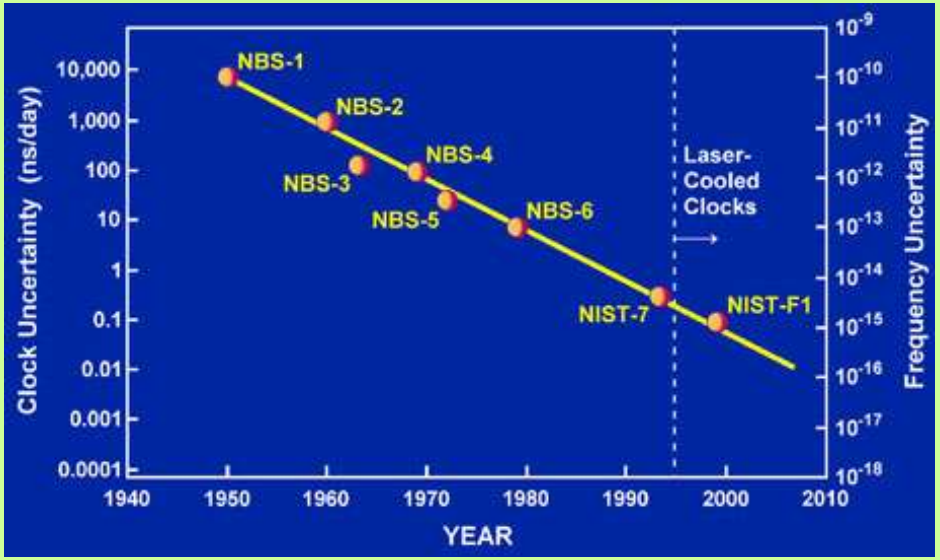


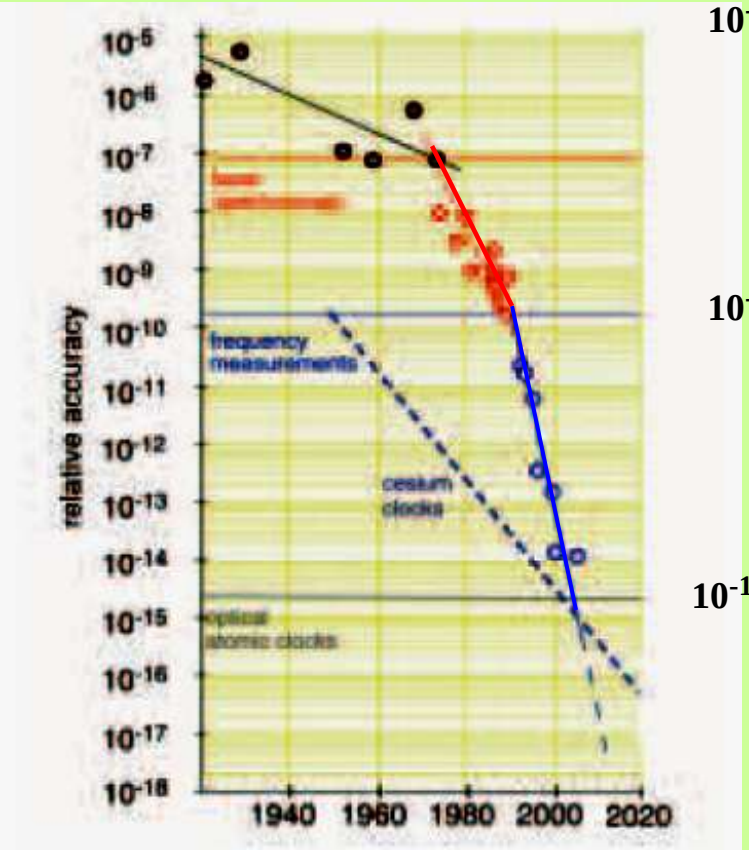
NBS 1955:1sec/300y





METAS/Switzerland 2004:1sec/30 000 000y






Accuracy of the Rydberg constant

basis for next time standard?

**Willis Lamb (1913-2008)**

## Nobel Prize 1955

"for his discoveries concerning the fine structure of the hydrogen spectrum"

# Lamb shift 1947

PHYSICAL REVIEW VOLUME 72, NUMBER 3 AUGUST 1, 1947

**Fine Structure of the Hydrogen Atom by a Microwave Method* ****

WILLIS E. LAMB, JR. AND ROBERT C. RETHERFORD
*Columbia Radiation Laboratory, Department of Physics, Columbia University, New York, New York*

(Received June 18, 1947)

$2s_{1/2}$ and $2p_{1/2}$ NOT degenerate

Bengt Edlén, Lund, observed in early 1930's significant deviation from Dirac theory in the fs for H-like ions.

**Existence of the shift known for some time**

**The origin quite mysterious**

**Oppenheimer suggested it was of quantum-el. dyn. origin**

**Lamb thought it was of different origin**

# The Hyperfine Structure of Atomic Hydrogen and Deuterium†

J. E. Nafe, E. B. Nelson, and I. I. Rabi
*Columbia University, New York, New York*
May 19, 1947

**Hyperfine separations differ from theory by 0.26 and 0.31 %**

**Well outside the limits of error**

**Rabi suspected erroneous fine-structure constant was used**

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

**Is the electron magn. mom. different from one Bohr magneton?**

### Does the Electron Have an Intrinsic Magnetic Moment?

G. BREIT
*Yale University, New Haven, Connecticut*
September 29, 1947

THE hyperfine structure of the ground term of $H^1$ and $H^2$ is greater[1] than expected from nuclear magnetic moments by, respectively, 0.26 and 0.31 percent. The difference between these values is less certain than the approximate value 0.28 percent and will be assumed to be insignificant.[2] If the electron had a small, Pauli-type, intrinsic magnetic moment[3] $\mu_e$ the observed and calculated values would differ.

**Gregory Breit (1899-1991)**

**Breit proposed deviation of order $\alpha\,\mu_B$**

# Expt'l verification of magn. mom. anomali 1948

PHYSICAL REVIEW VOLUME 74, NUMBER 3 AUGUST 1, 1948

## The Magnetic Moment of the Electron†

P. KUSCH AND H. M. FOLEY
*Department of Physics, Columbia University, New York, New York*

(Received April 19, 1948)

A comparison of the $g_J$ values of Ga in the $^2P_{3/2}$ and $^2P_{\frac{1}{2}}$ states, In in the $^2P_{\frac{1}{2}}$ state, and Na in the $^2S_{\frac{1}{2}}$ state has been made by a measurement of the frequencies of lines in the *hfs* spectra in a constant magnetic field. The ratios of the $g_J$ values depart from the values obtained on the basis of the assumption that the electron spin gyromagnetic ratio is 2 and that the orbital electron gyromagnetic ratio is 1. Except for small residual effects, the results can be described by the statement that $g_L = 1$ and $g_S = 2(1.00119 \pm 0.00005)$. The possibility that the observed effects may be explained by perturbations is precluded by the consistency of the result as obtained by various comparisons and also on the basis of theoretical considerations.

$$\mu_S = 1.00119(5)\ \mu_B$$

These results are not in agreement with the recent suggestion by Breit[6] as to the magnitude of the intrinsic moment of the electron.

**Polykarp Kusch (1911-1993)**

## Nobel Prize 1955

"for his precision determination of the magnetic moment of the electron"

# Influence of the war

**MIT Radiation Laboratory**

**Established in Oct. 1940 by NDRC (National Defence Research Committee) for the purpose of improving radar**

**Lee DuBridge director, Rabi dep. director, dir. of research**

**”All research had to be useful”**

**RADAR (RAdio Detection And Ranging)**

**Developed in England around 1935,**
**10 m (30 MHz) 1939 1.5 m (600 MHz)**

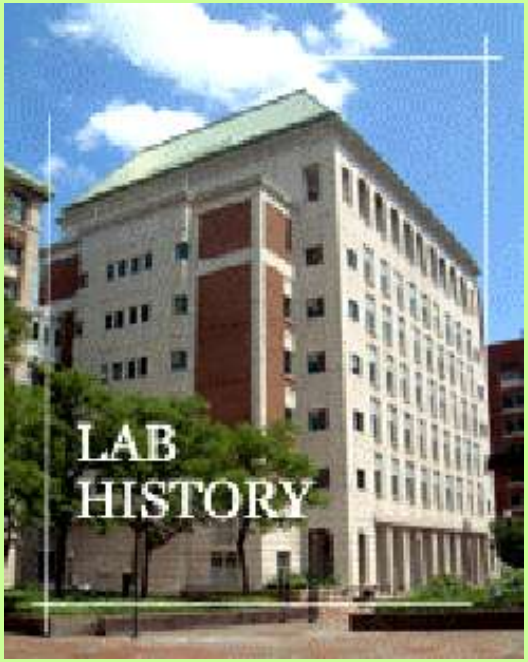
**Magnetron developed in England 1940**
**Could generate frquencies up to 3 GHz (10 cm)**
**Brought to USA in 1940**

**Improved at Rad. Lab. to 10 GHz (3cm)**

**1940 $0.5M 50 people**

**1945 $40M 4000 people**

# Columbia Radiation Laboratory




**Branch of MIT Rad. Lab.**

**Established in 1942 under directorship of Isaac Rabi**
**Continued development of radar down to 1 cm**

**Access to Radar had enormous impact on the war**

**Churchill: ”Battle of the Atlantic”**

**Sinking of ”BISMARCK” in May 1941 turning point**

**”Science changed the course of World History”**

**The work with radar during the war led to the development of microwave spectroscopy, quantum-electrodynamics**

**which led to the development of the MASER**

**which led to …..**

**” World History changed the course of Science ”**

# Shelter Island Conference 1947

# Rebirth of Quantum-Electro-Dynamics (QED)

Lamb, Oppenheimer, Darrow, Weisskopf, Uhlenbeck, Kashak, Schwinger, Bohm

Pais, Feynman, Feshbach

# Problems with QED

**Basic theory Dirac, Pauli, Heisenberg late 1920's, Vacuum polarization**

**Serious divergencies  Great dispair**

**Heisenberg to Pauli 1935: "We know that everything is wrong"**

**Oppenheimer: Maybe differences are finite?**

**Charge renormalization Heisenberg, Weisskopf 1936**

**NOT ENOUGH**

**Electron self energy only log. divergent Weisskopf 1934**

**Mass renormalization Kramers, Weisskopf 1940 …**

**Bethe showed 1947 that charge and mass renormalization works**

**Non.rel. calc. of Lamb shift: 1040 MHz, Lamb: 1000 MHz (1057 MHz)**

**Hans Bethe (1906-2005)** **99 years!**

**Nobel Prize 1967**

**Victor Weisskopf 1908-2002**

**Relativistic calc. of Lamb shift (w French) 1948**

**Julian Schwinger 1918-1994**

**Calculated 1948 the g-factor of the electron to be**

$$g_s = 2(1+\alpha/2\pi+\ldots) = 2\text{x}1.00116\ldots$$

**Kusch-Foley:** $g_s = 2\text{x}1.00119(5)$

**Dyson showed 1949 that the formulations of Feynman and Schwinger were equivalent**

**Also showed that charge and mass renormalization removes the singularities to all orders of perturbation theory**

**Freeman Dyson 1923-**

# Nobel Prize 1965

"for their fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles"

**Sin-Itiro Tomonaga**
**1906-1997**

**Julian Schwinger**
**1918-1994**

**Richard P. Feynman**
**1918-1988**

**Robert Oppenheimer (1904-1967)**

**Enrico-Fermi award 1963**

**”Father of the atomic bomb”**

**Born-Oppenheimer**

**QED**

**Two-meson theory (Marshak)**

**Black holes (**Chandrasekhar NP 1983)

**1947 Dir. Princeton Inst. Adv. Study**

**1946 Chairm. Advisor Comm. AEC**

**1954 removed (McCarthy, Teller)**

**Argued against Hiroshima, Nagasaki**

**Strongly against H-bomb**

**Bhagavad Gita: ”Now I am become Death, the destroyer of the world”**


Oppenh1htm

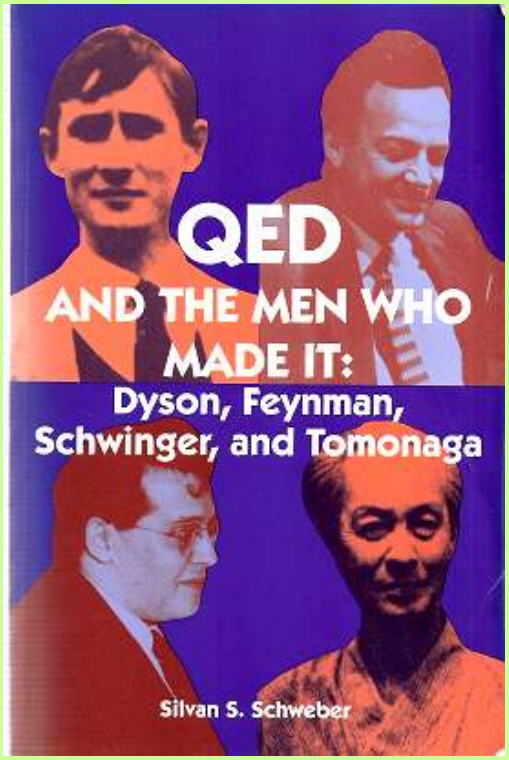

Oppenheimer2.htm


Oppenh3htm

**J.Schweber: QED and the men who made it:**

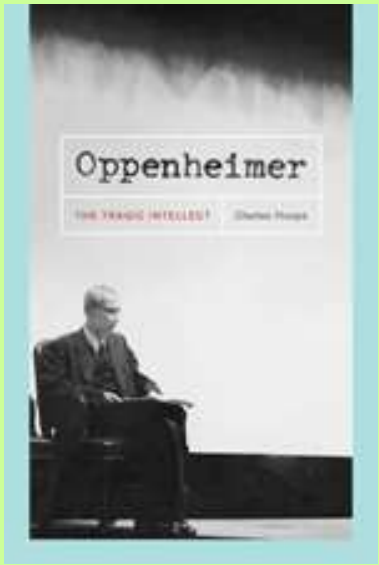
**Dyson, Feynman, Schwinger, and Tomanaga**

**(Princeton Univ. Press 1994)**




**Charles Thorpe:**

**Oppenheimer, The tragic intellect (Univ. Chicago 2006)**



**Since the mid 1930's nuclear and particle physics considered as the font lines of physics**

**The experiments of Rabi and his team shifted the focus to a large extent towards atomic physics and QED**

# New optical resonance methods invented 1949-50

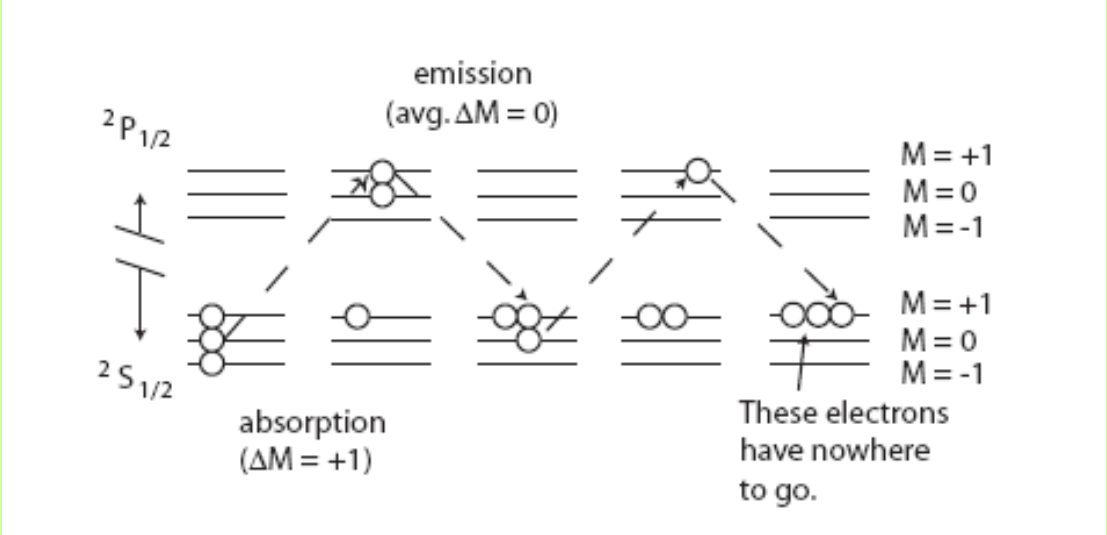
## Optical pumping, Optical double resonance

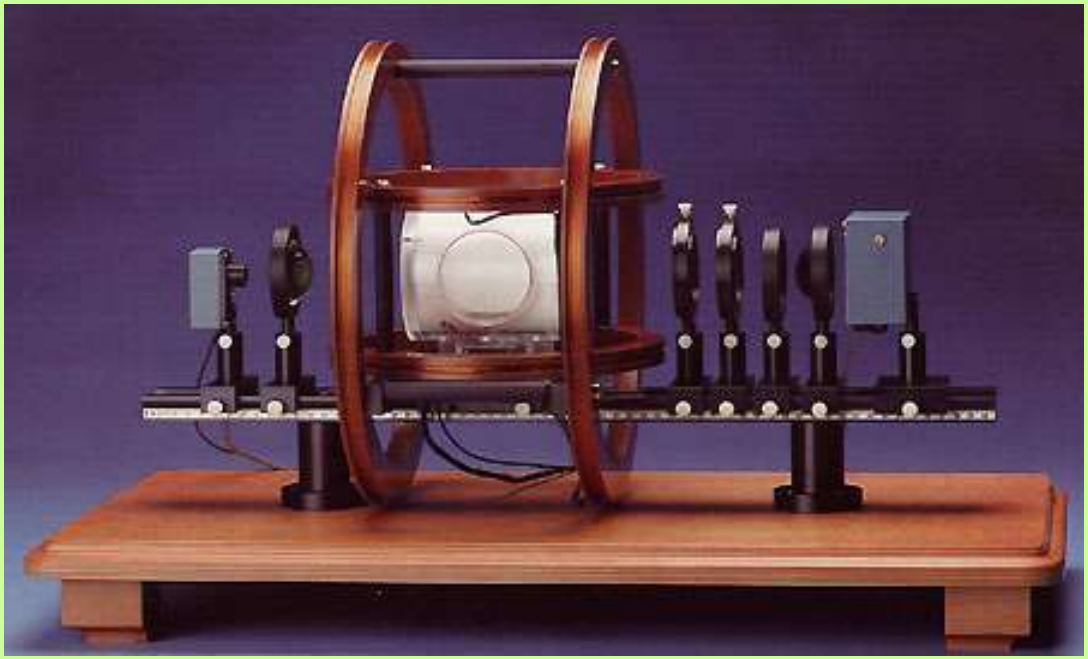
**Alfred Kaster 1902-1984**

**Nobel Prize 1966**

**Jean Brossel 1918-2003**

"for the discovery and development of optical methods for studying Hertzian resonances in atoms"



**Rabi's A and B magnets replaced by optical light**

# Hans Kopfermann's optical laboratory

## Philosophenweg, Heidelberg

**Andreas Steudel, Herbert Walther, Hans Bucka,**

**Sigfried Penselin, Gisbert zu Putlitz, Ernst Otten**

**Leading optical institute at the time**

**Started early work with optical resonance methods**

# Brookhaven Conferences on Molecular Beams

**arranged by Bill Cohen from 1955**

**every or every-second year**

**Ingvar attended them from 1956**

**Important meeting place**

**Atomic/molecular beams was the HOT topic at the time**

**In 1956 Ingvar visited the main atomic-beam laboratoris in USA, among them**

**Joe Hamilton's Atomic-Beam Laboratory, Princeton**

THE REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 26, NUMBER 12 DECEMBER, 1955

## Focusing Atomic Beam Apparatus*

**1955**

AARON LEMONICK,† FRANCIS M. PIPKIN,‡ AND DONALD R. HAMILTON
*Palmer Physical Laboratory, Princeton University, Princeton, New Jersey*
(Received August 16, 1955)

The construction and design principles of a focusing atomic beam apparatus are reported. This apparatus, which is of the radio-frequency magnetic resonance type and which has been used to measure the spins and hyperfine splittings of four radioactive nuclides as reported elsewhere, utilizes the six-pole focusing magnet of Friedburg and Paul and of Korsunskii and Fogel but in a way which avoids velocity aberrations. From an analysis of the optimization of intensities in the conventional and the focusing types of atomic beam apparatus it is concluded that the latter has an advantage of a factor of roughly twenty-five.

**Francis Pipkin, Henry Stroke, Will Happer**

## 1964 Brookhaven conference in Uppsala

**Broadened scope to include optical resonance**

**Brookhaven Atomic-Beam Conference was in 1968**

**converted to**

**International Conference on Atomic Physics**

# ICAP

**1982 ICAP in Gothenburg**

**arranged by Ingvar, Sune and Arne**

# Local activity

**1966 Ingvar moves from Uppsala with Arne Rosén to Gothenburg**

**Upon recom. by Ingvar Marklund we recruted Sune, Curt Ekström, Håkan Nykvist**

**Arne, Curt and Håkan work with atomic beams**

**Sune start to study optical resonance methods**

**Went 1967 to Bucka in Berlin**

**Then start to set up an optical resonance group in Gothenburg**

**Sune post.doc. with Will. Happer at Columbia 1972-73**

# First tunable dye laser comm. available 1972

**Sune responsible for the first dye-laser equipment at Columbia**

**After returning home starts to set up a laser lab in Gothenburg**

**In 1980 Sune moves to Lund**

**to start Lund Laser Center**


**End of prehistory**

**Thank you, Sune !**

**Happy retirement !**