20th Century Research: *From Basic to Translational* 21st century?

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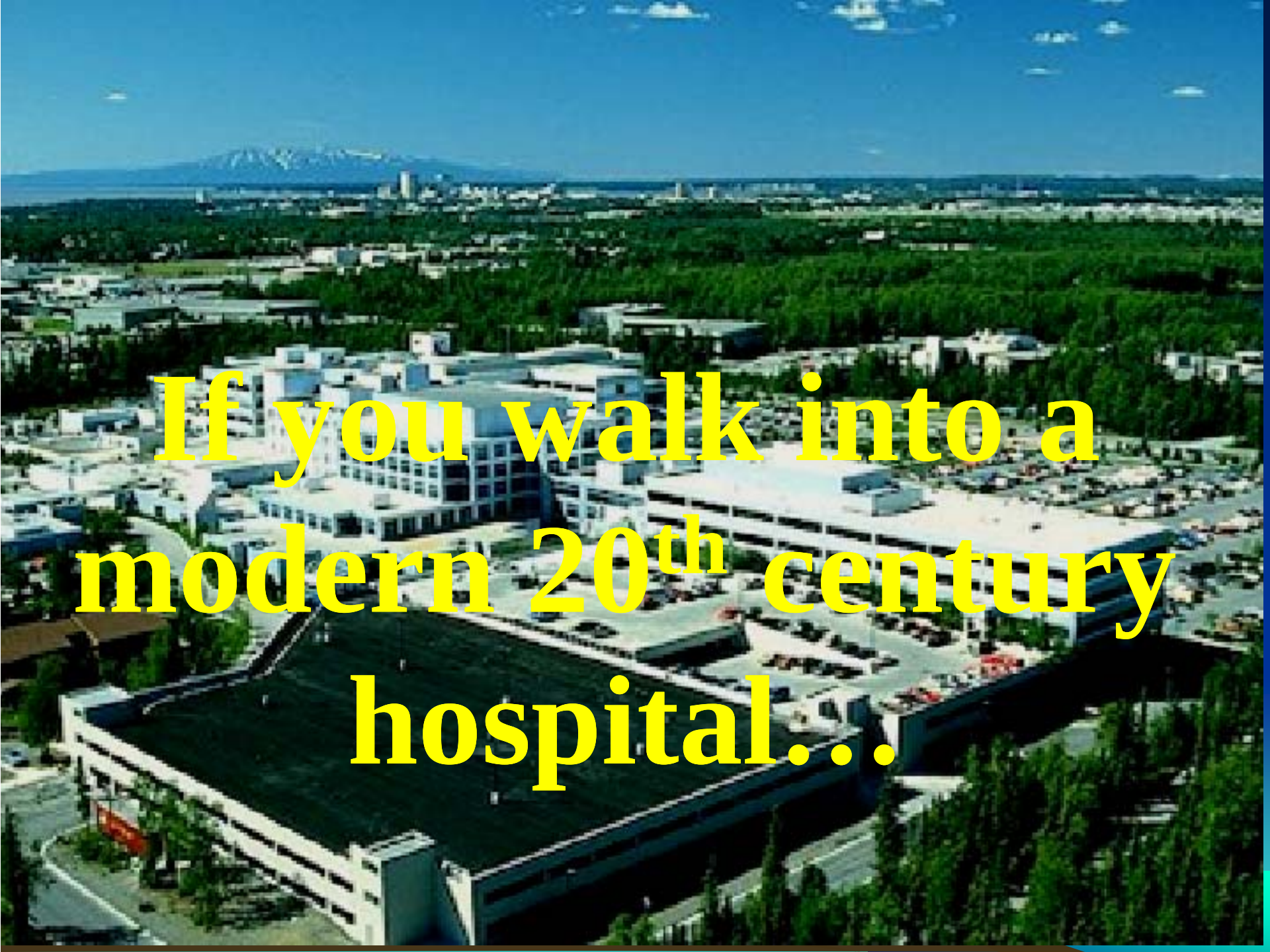
Senior Vice President
National Tsing Hua University

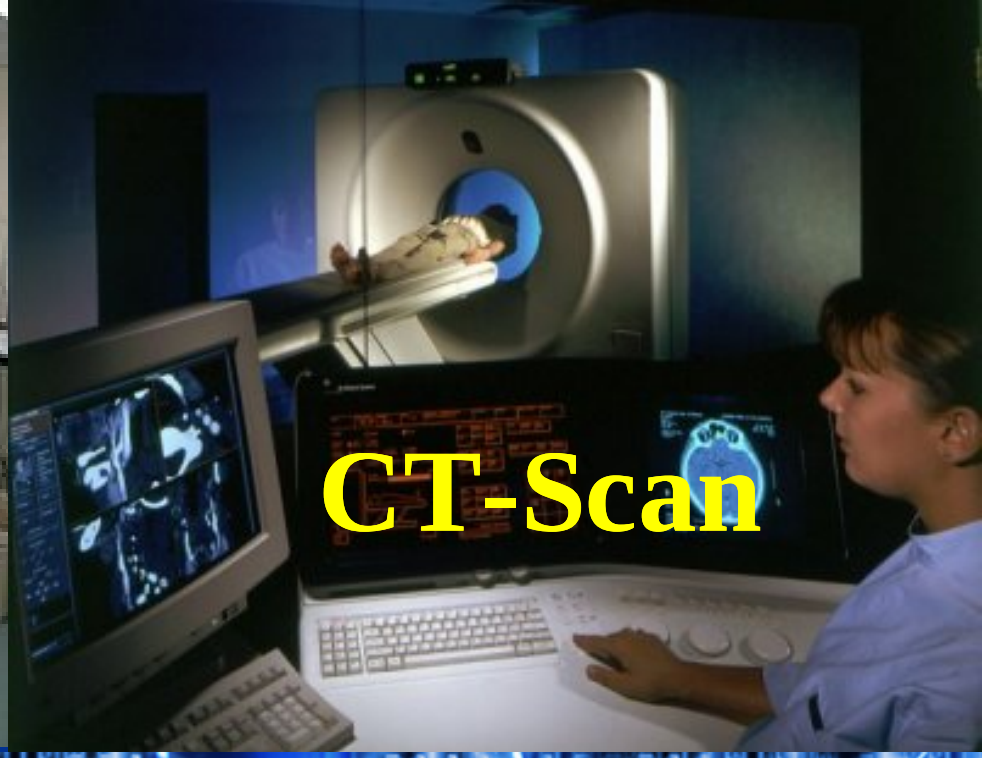
A presentation to students at Malaysia's Universiti Tecknologi Petronas : A pre-ESTCON (The World Engineering, Science and Technology Congress) conference meeting.

June 11, 2012

Ipoh, Malaysia

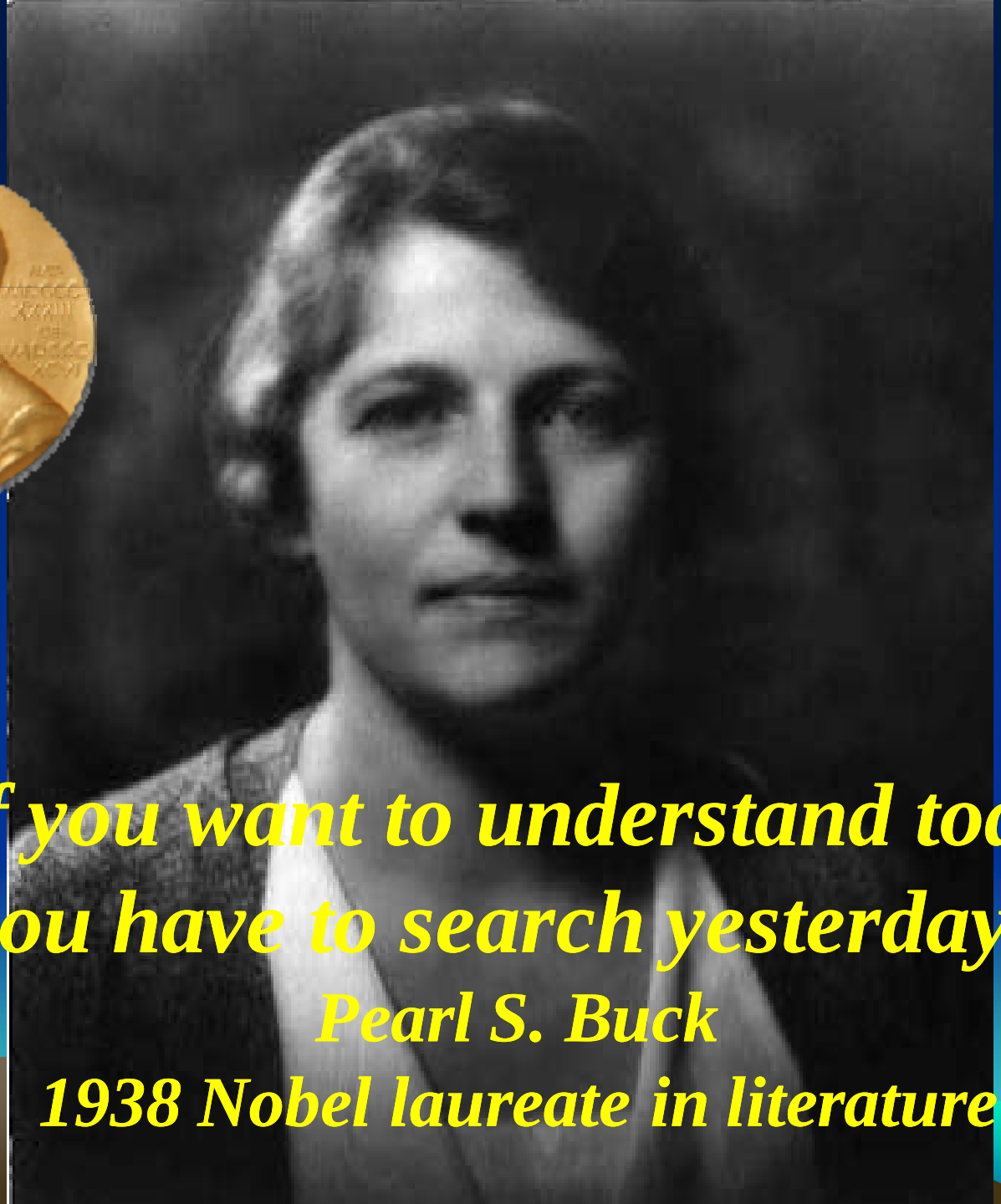

If you walk into a modern 20th century hospital…


PET


CT-Scan


MRI


Internet



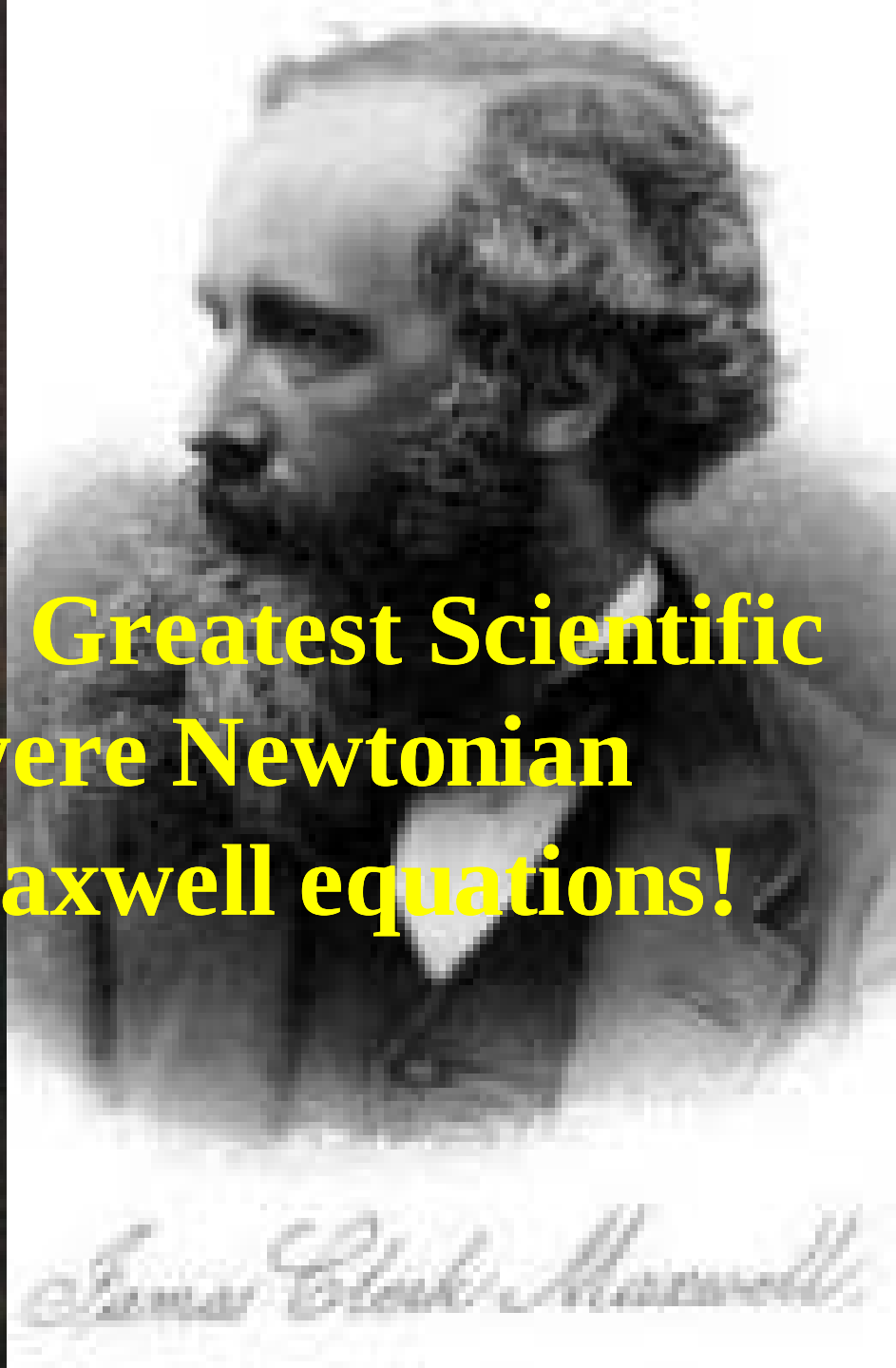
"If you want to understand today, you have to search yesterday."

Pearl S. Buck

1938 Nobel laureate in literature

Renaissance

Rise of the European intellectual powerhouses with modern scientific methodologies



17 and 19 Centuries Greatest Scientific achievements were Newtonian Mechanics and Maxwell equations!

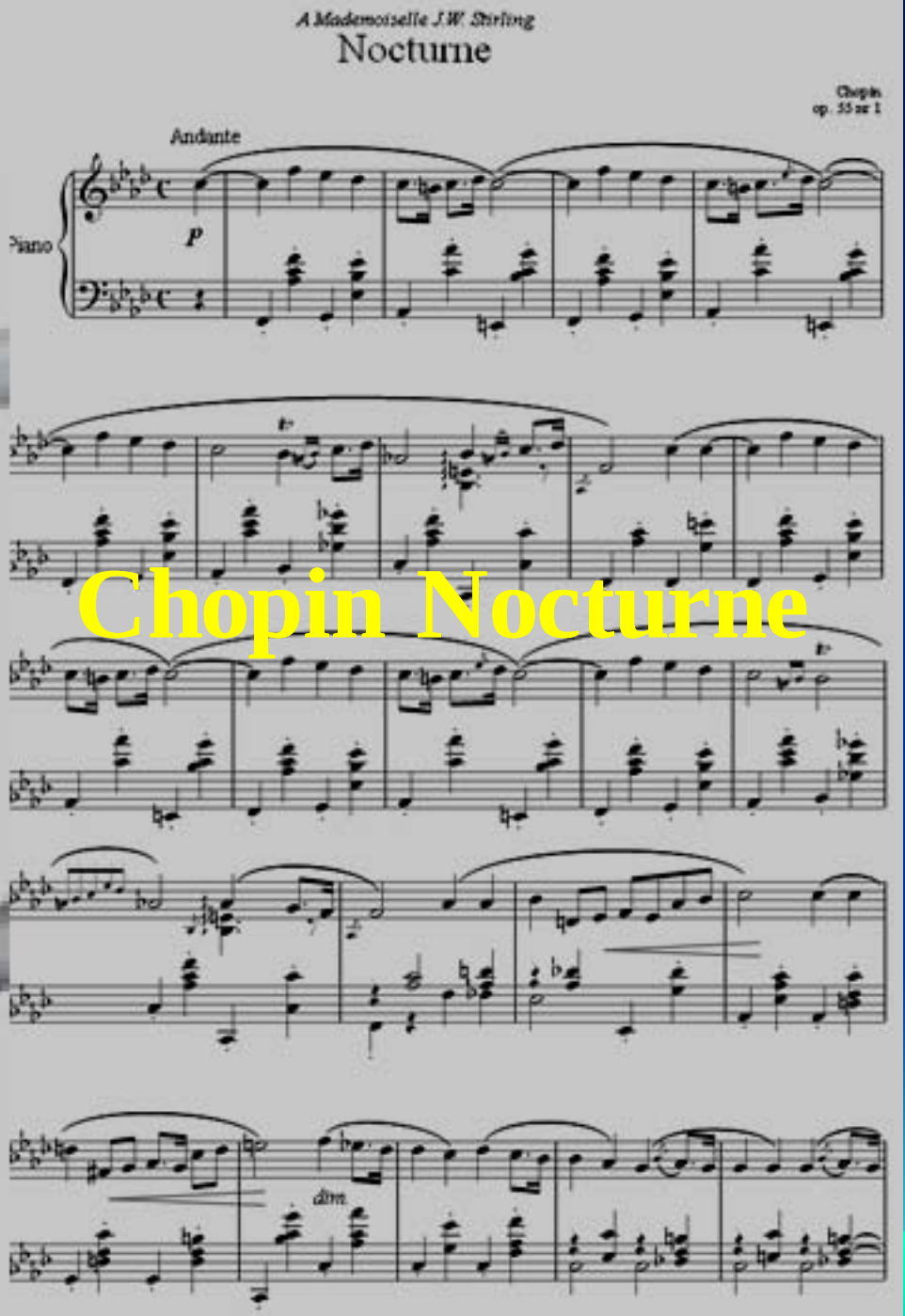
Maxwell Equations Chopin Nocturne

$$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\varepsilon_0}$$

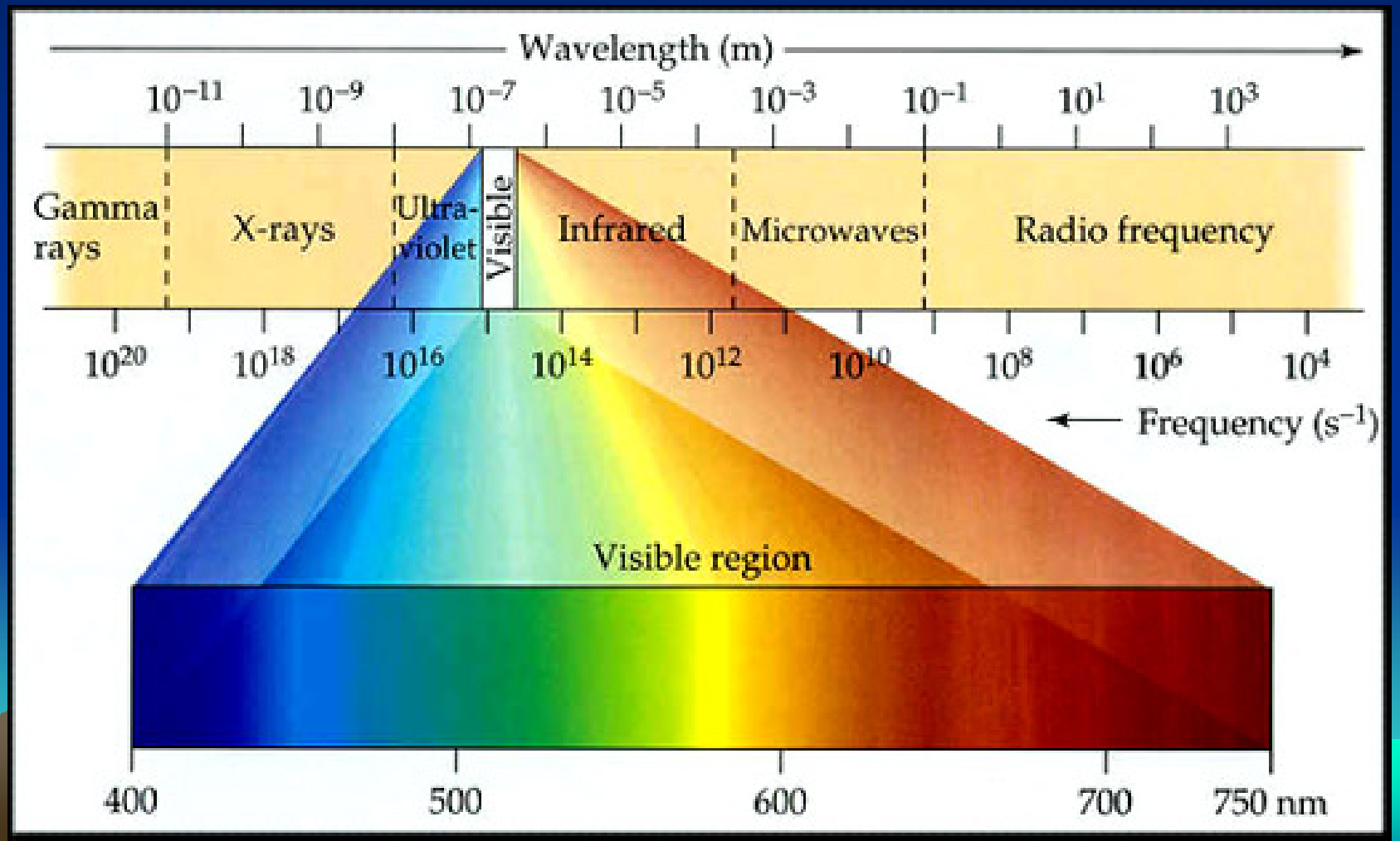
$$\oint \vec{B} \cdot d\vec{A} = 0$$

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 i + \frac{1}{c^2}\frac{\partial}{\partial t}\int$$



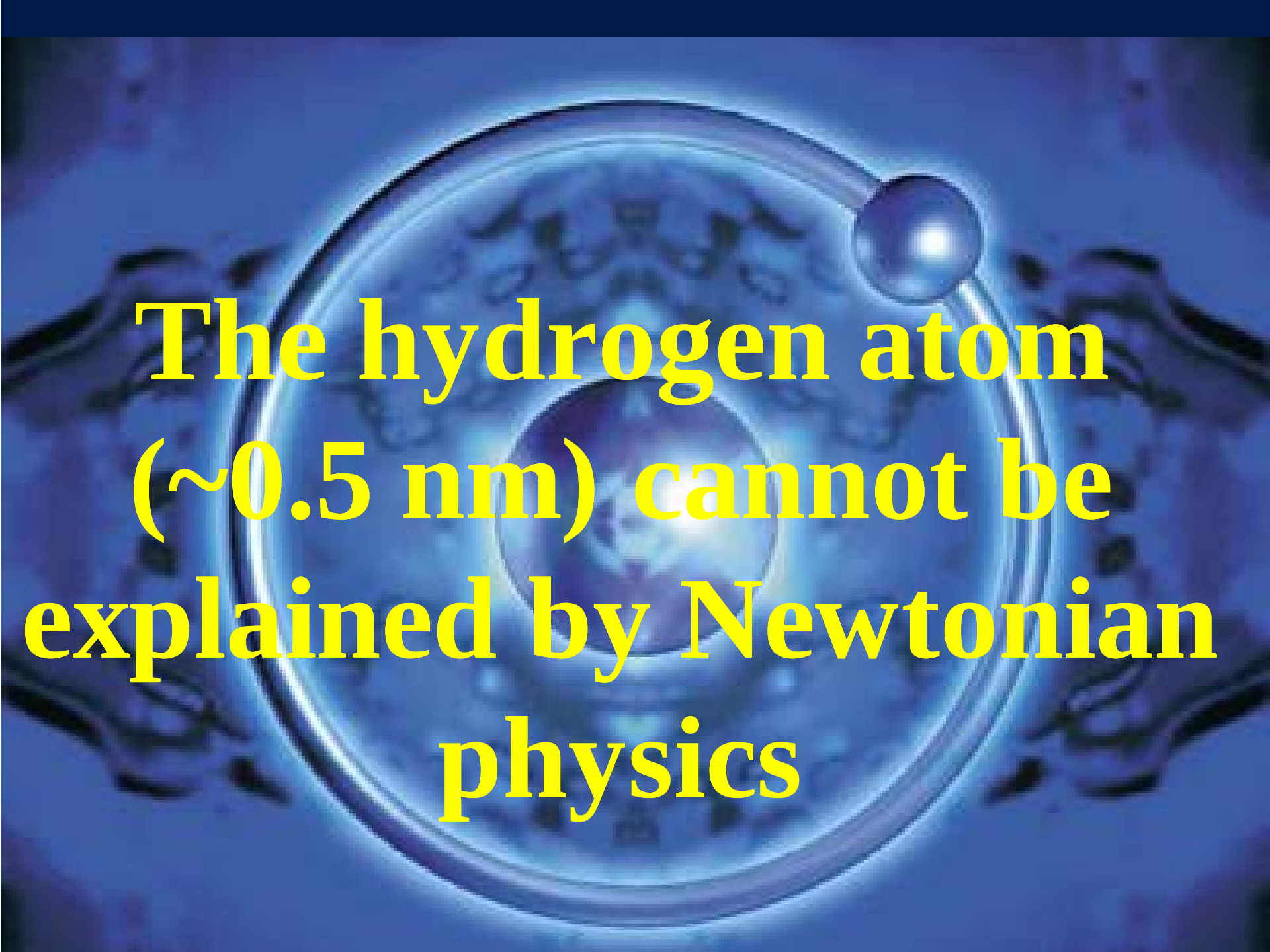
Maxwell equations give a complete understanding of electromagnetic "radiation"

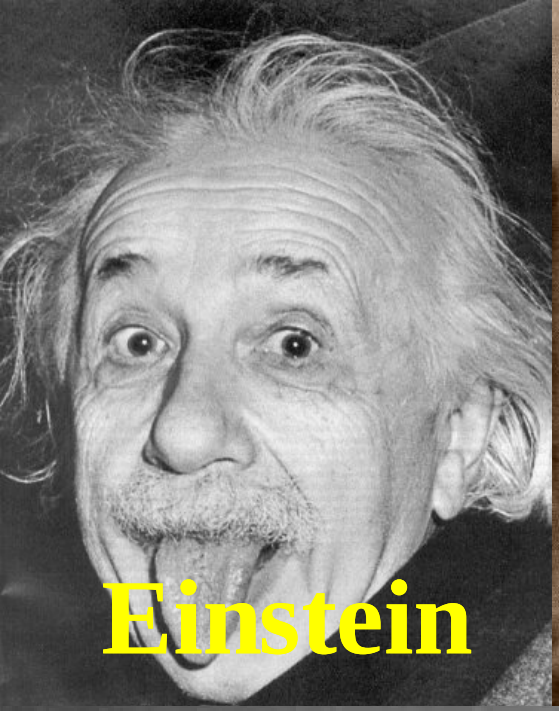


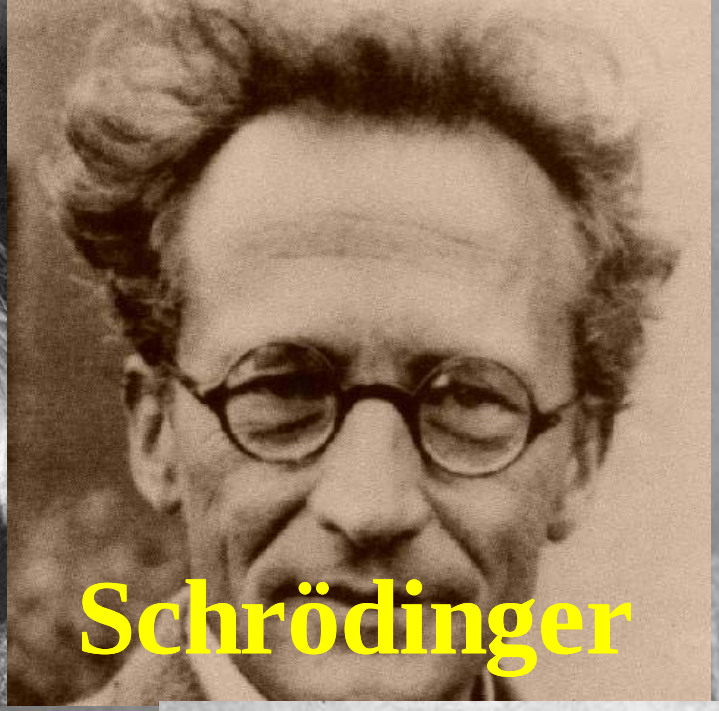
Scientific and technological relevant to health issues in the 20th century

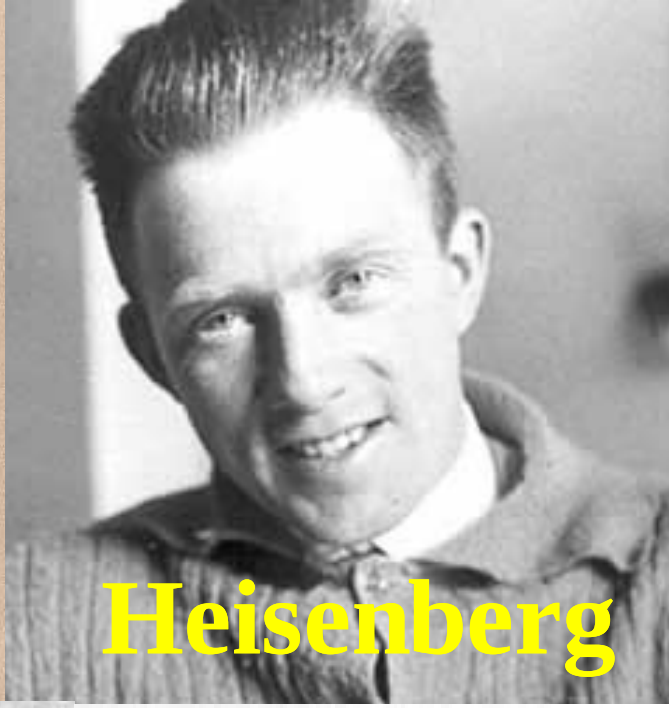
- Smaller
- Colder
- Faster communications


scattered
electron
incident
electron
Smaller
How to understand the
“micro-world”?
knocked-out
proton
correlated partner
proton or neutron

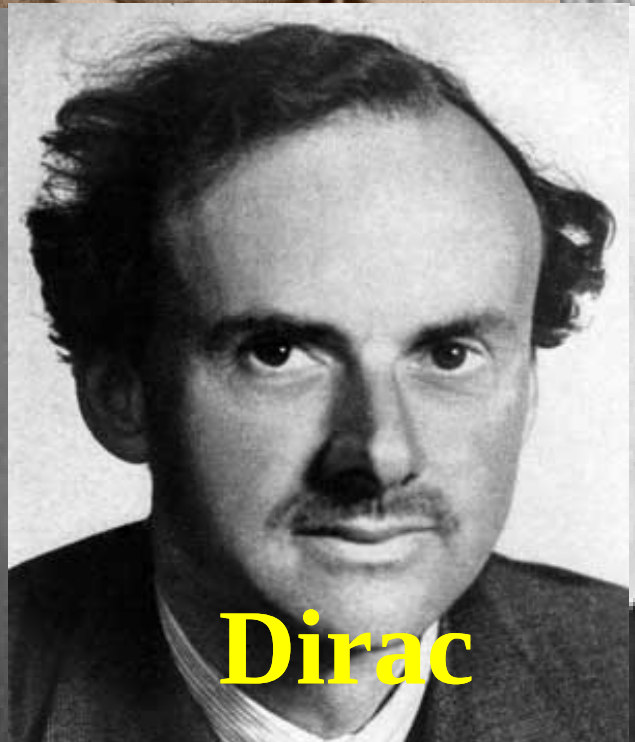

The hydrogen atom (~0.5 nm) cannot be explained by Newtonian physics


Einstein


Schrödinger


Heisenberg


Bohr


Dirac


Pauli

$$H(t)\,|\,\psi(t)\rangle = i\hbar\frac{d}{dt}\,|\,\psi(t)\rangle$$

$$\left(\beta mc^2 + \sum_{k=1}^{3}\alpha_k p_k\,c\right)\psi(\mathbf{x},t) = i\hbar\frac{\partial\psi}{\partial t}(\mathbf{x},t)$$

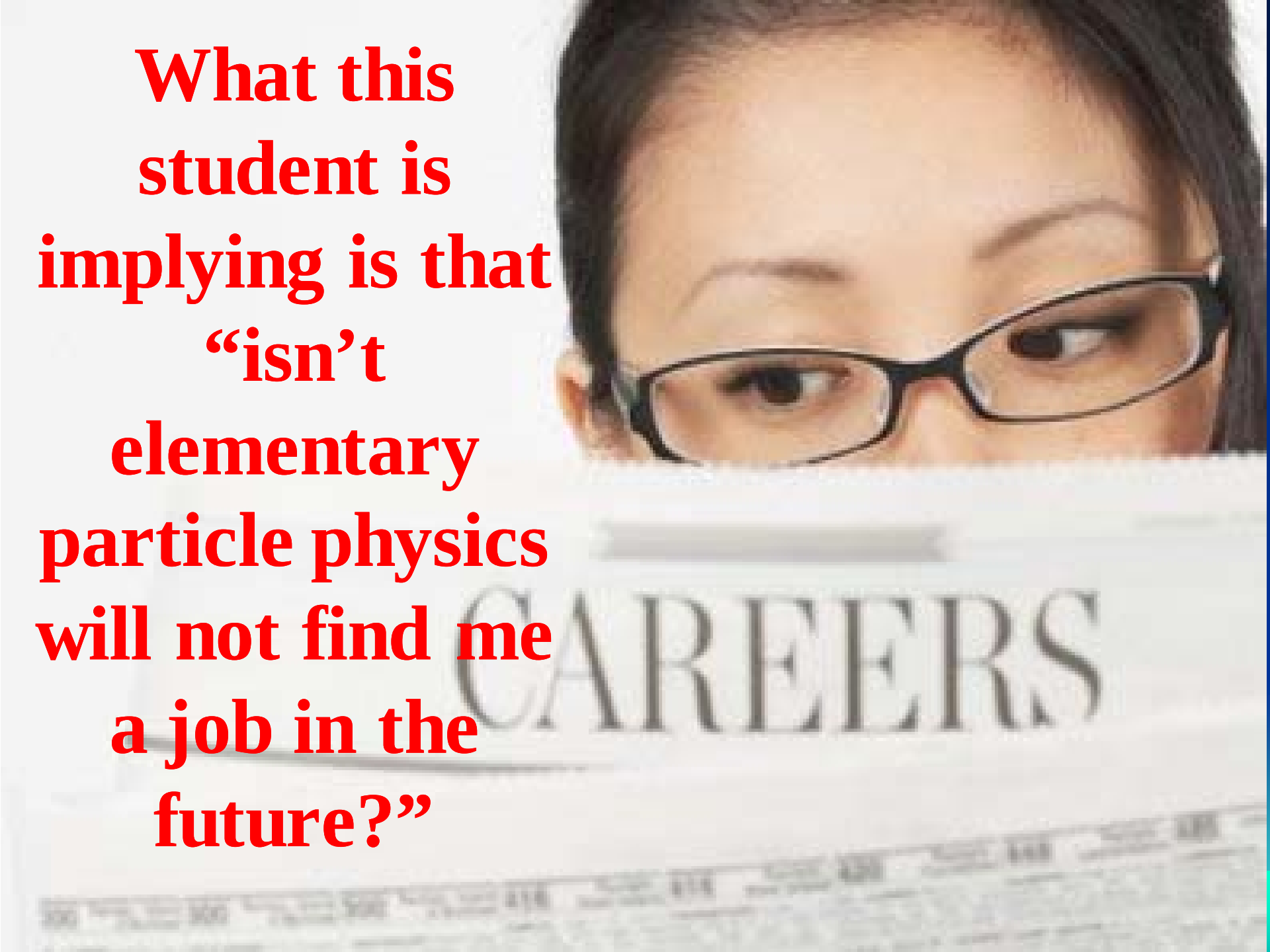
Quantum Mechanics

gives rise to detailed understanding of the micro-world

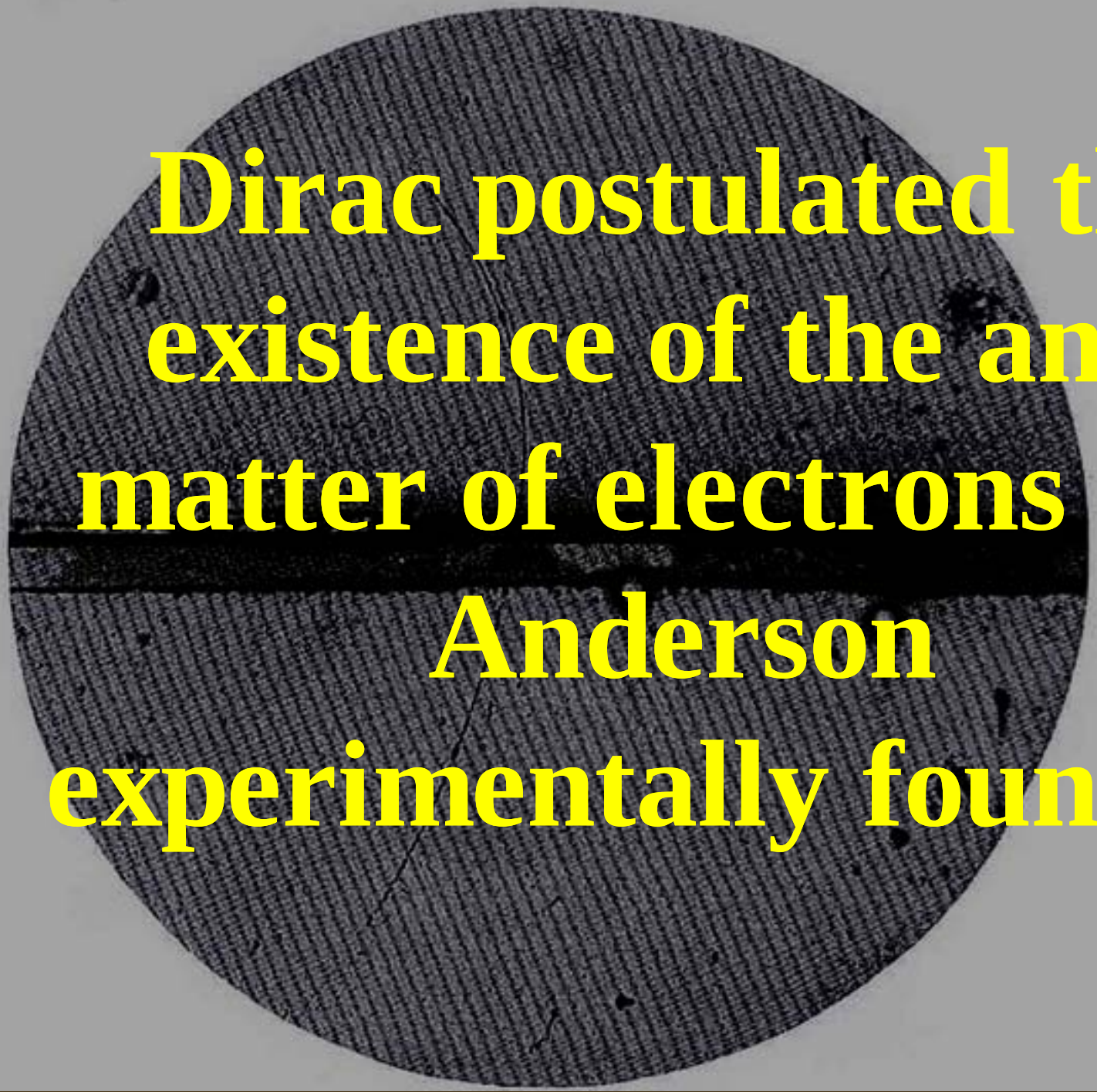
A highschool student in 1993 in Chung-Li (中壢) asked MIT's Professor, the late-Herman Feshbach, the following provocative question :

"Why should I study elementary particle physics?"

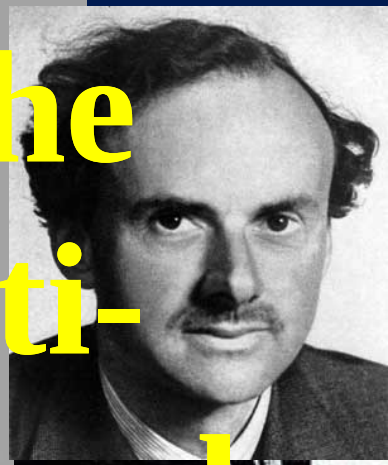
What this student is implying is that "isn't elementary particle physics will not find me a job in the future?"

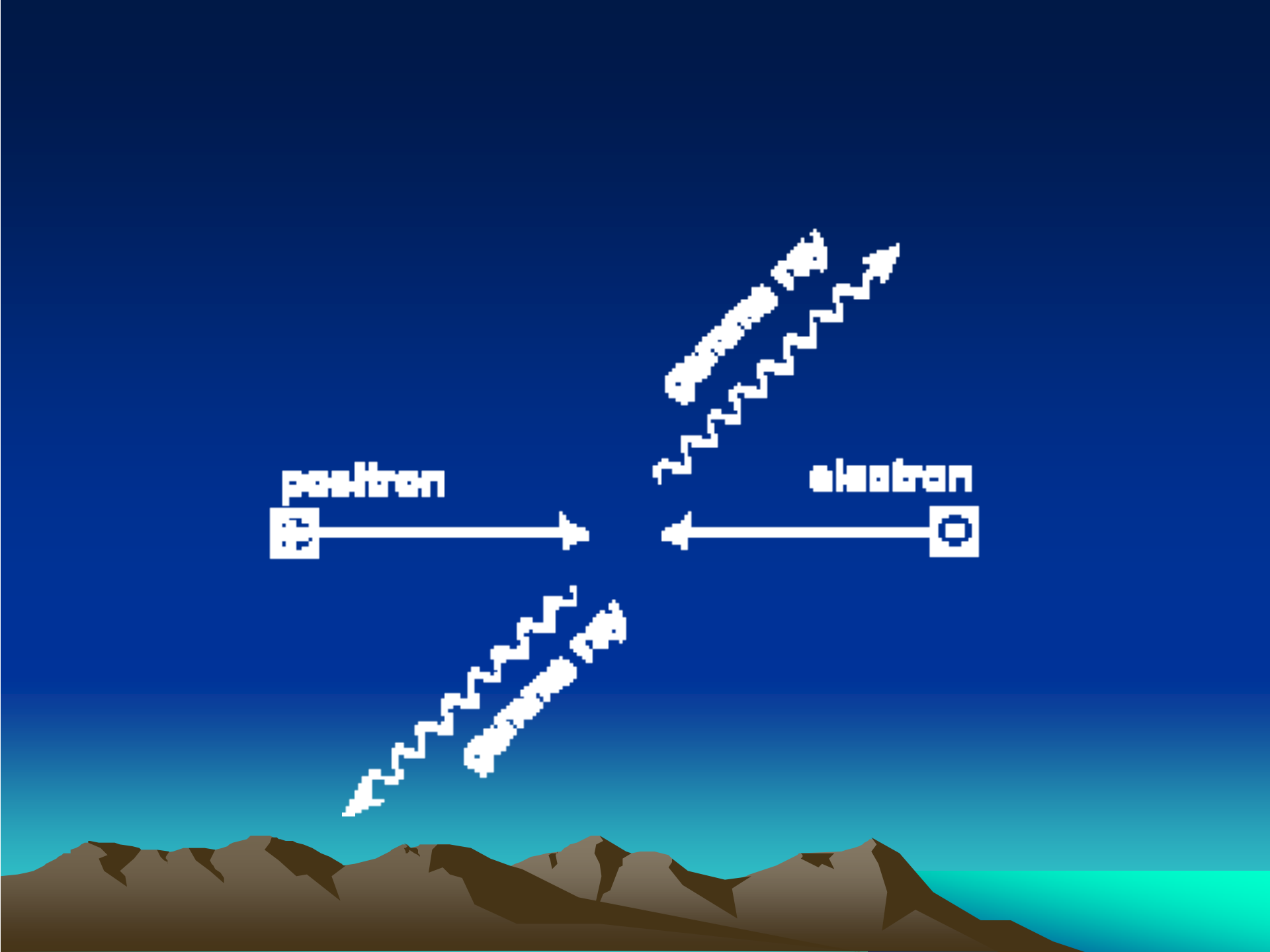


“You should learn it because only then can you “trick” nature into doing something that could be beneficial for humanity!”

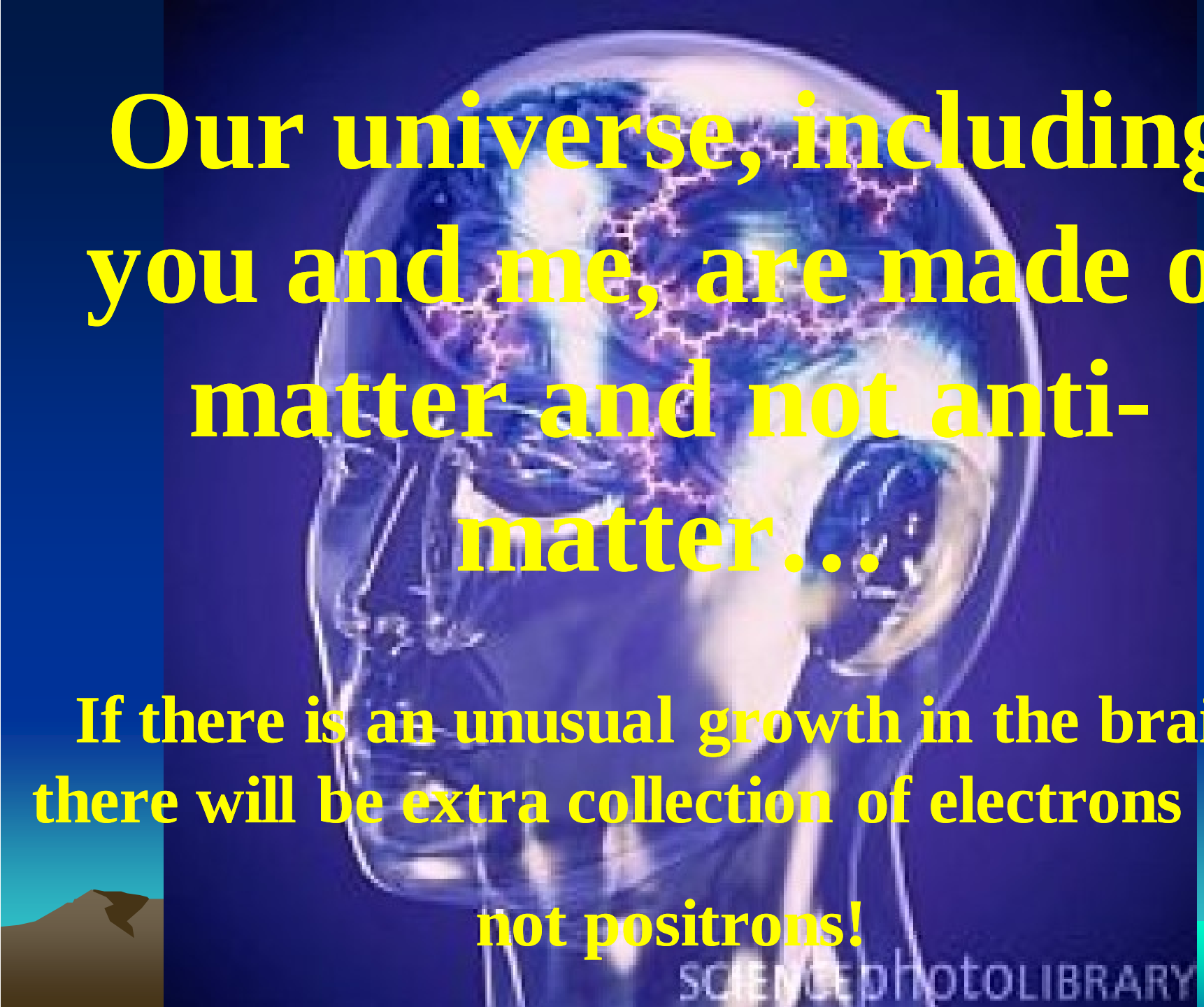


Dirac postulated the existence of the anti-matter of electrons and Anderson experimentally found it!




positron
electron

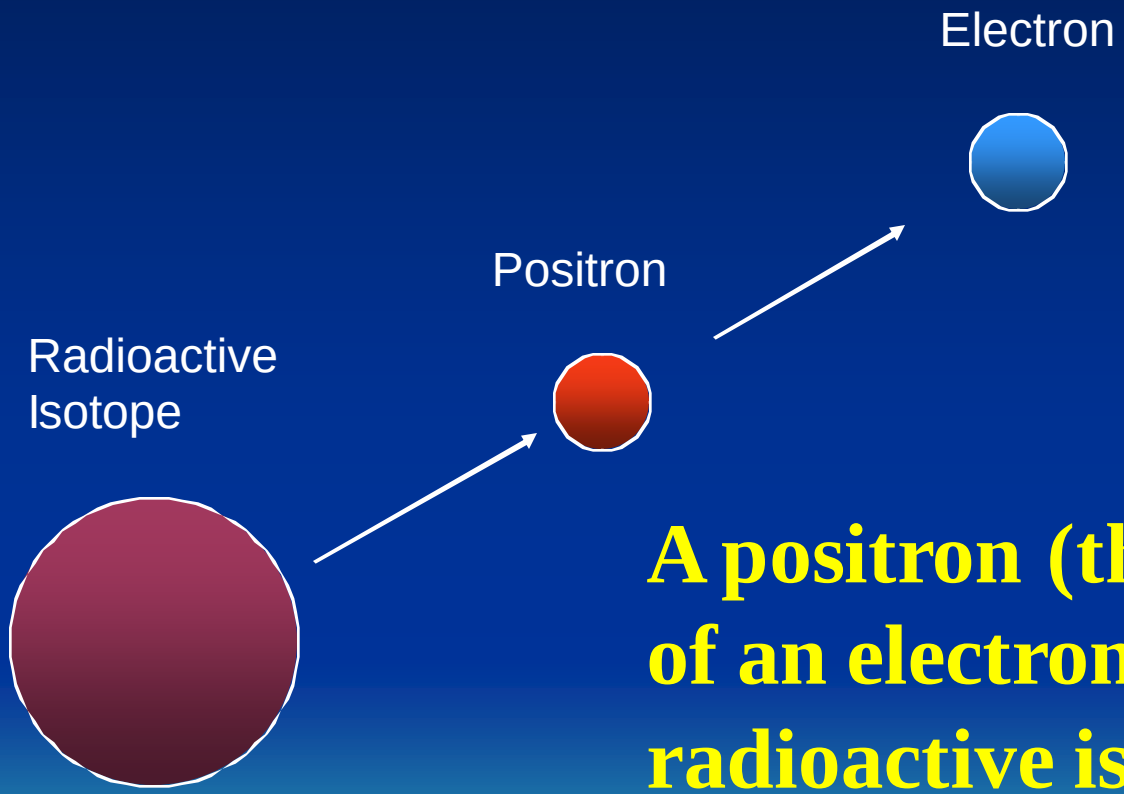
Our universe, including you and me, are made of matter and not anti-matter…



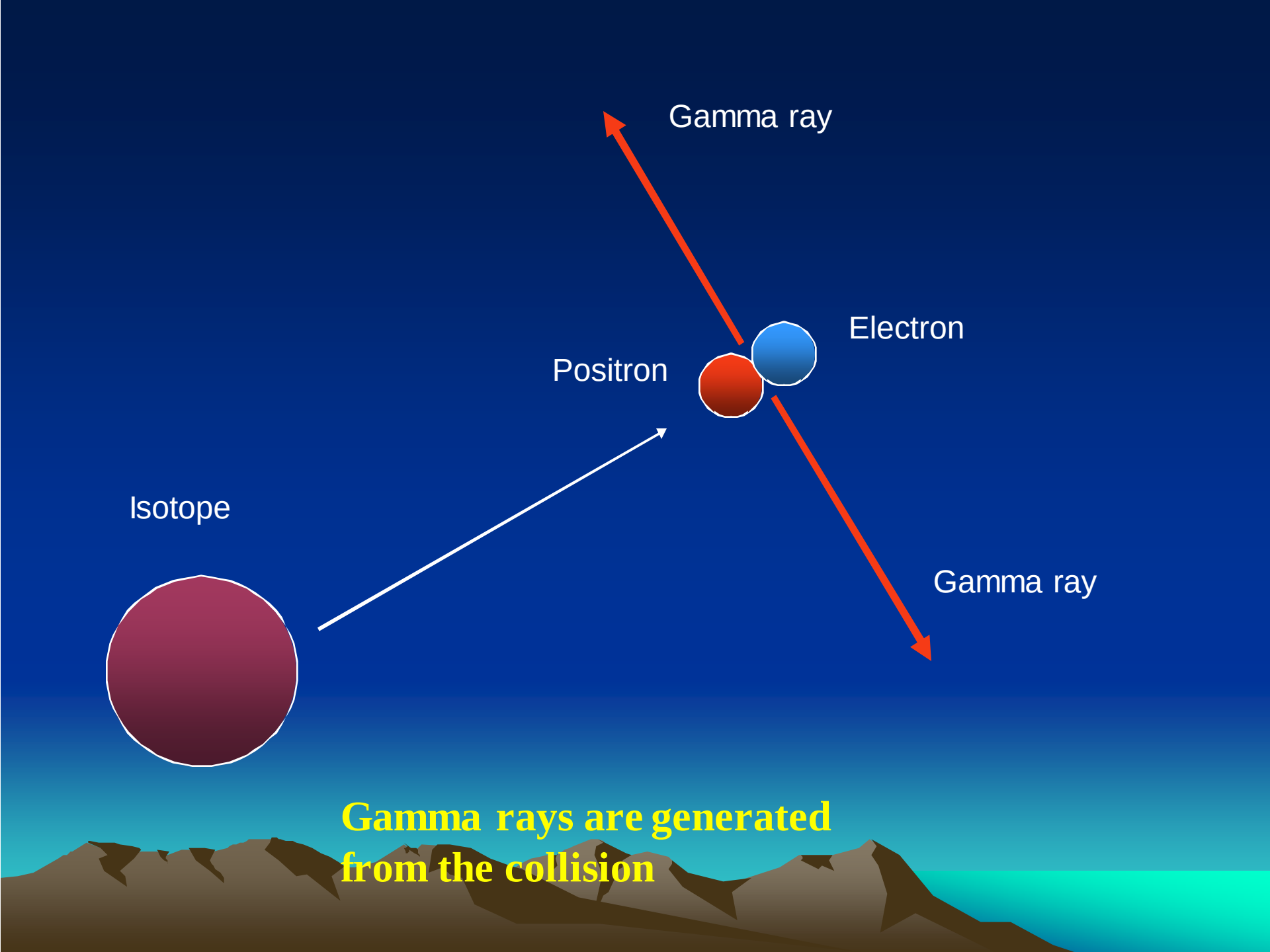
If there is an unusual growth in the brain, there will be extra collection of electrons and not positrons!

So to detect the unusual growth, all you need to do is to shot positrons into the brain, and if you see extra gamma rays coming out, you can deduce that there must be something unusual at the point in the brain…

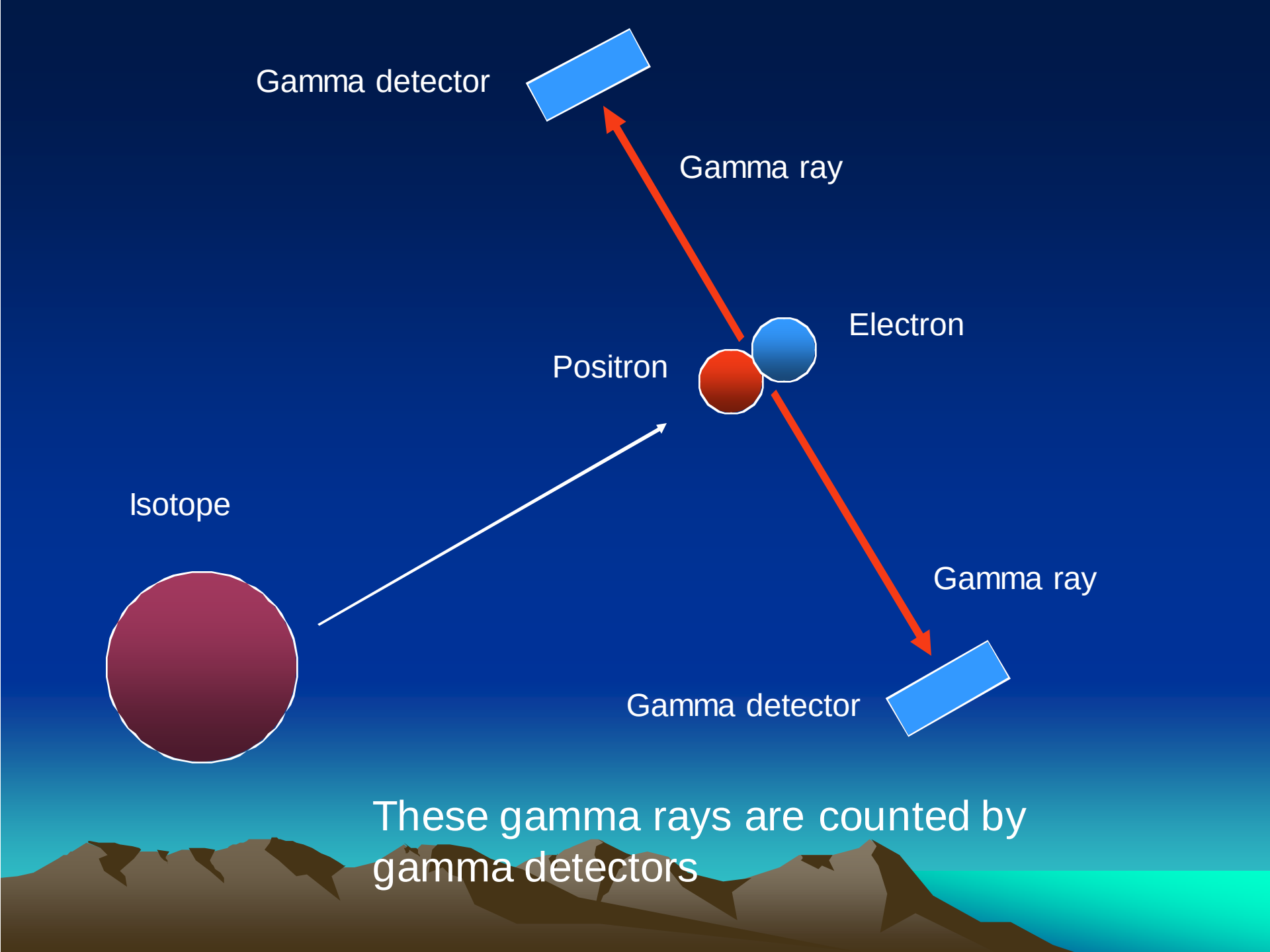
This is the science. The rest is engineering!



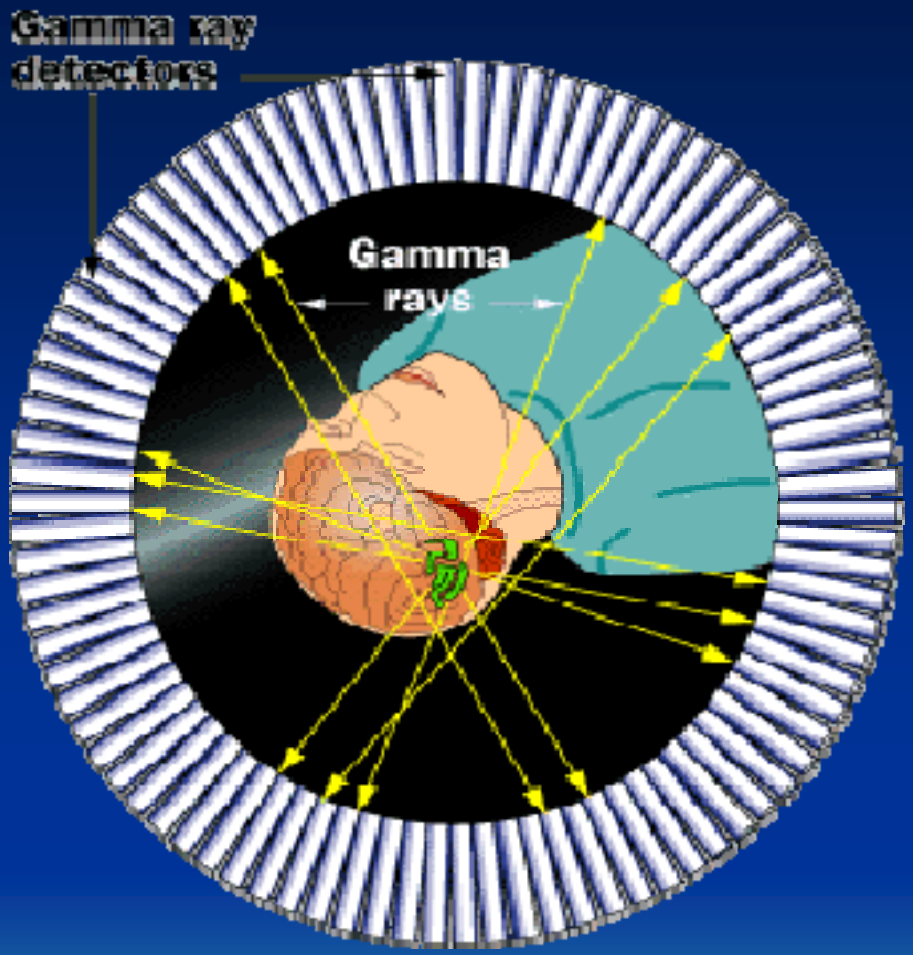
A positron (the anti-matter of an electron) emitted from radioactive isotope collides with an electron

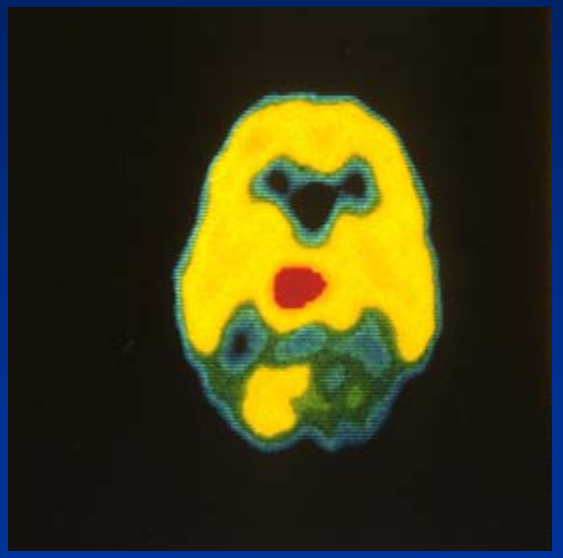


Gamma rays are generated from the collision



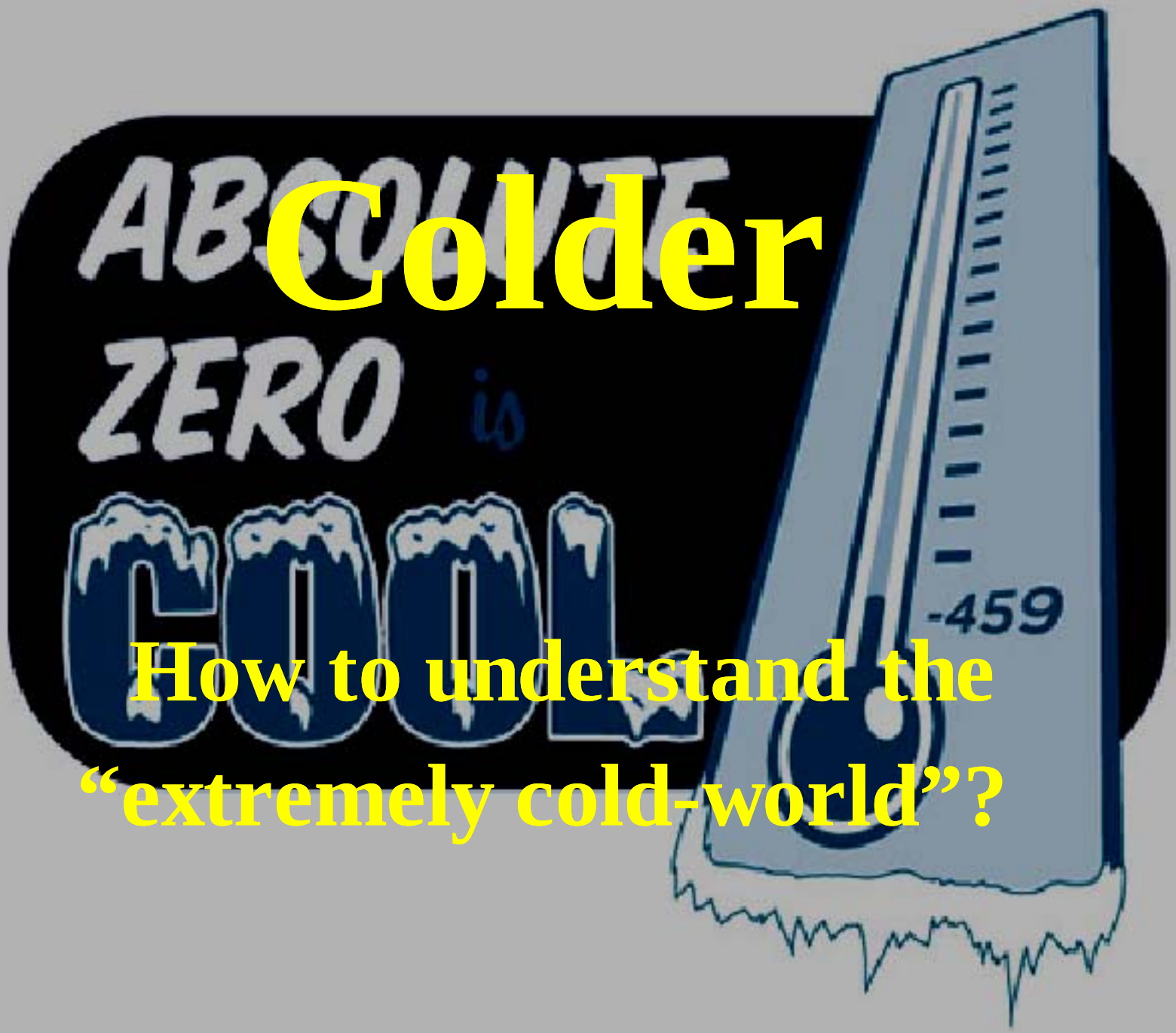
These gamma rays are counted by gamma detectors



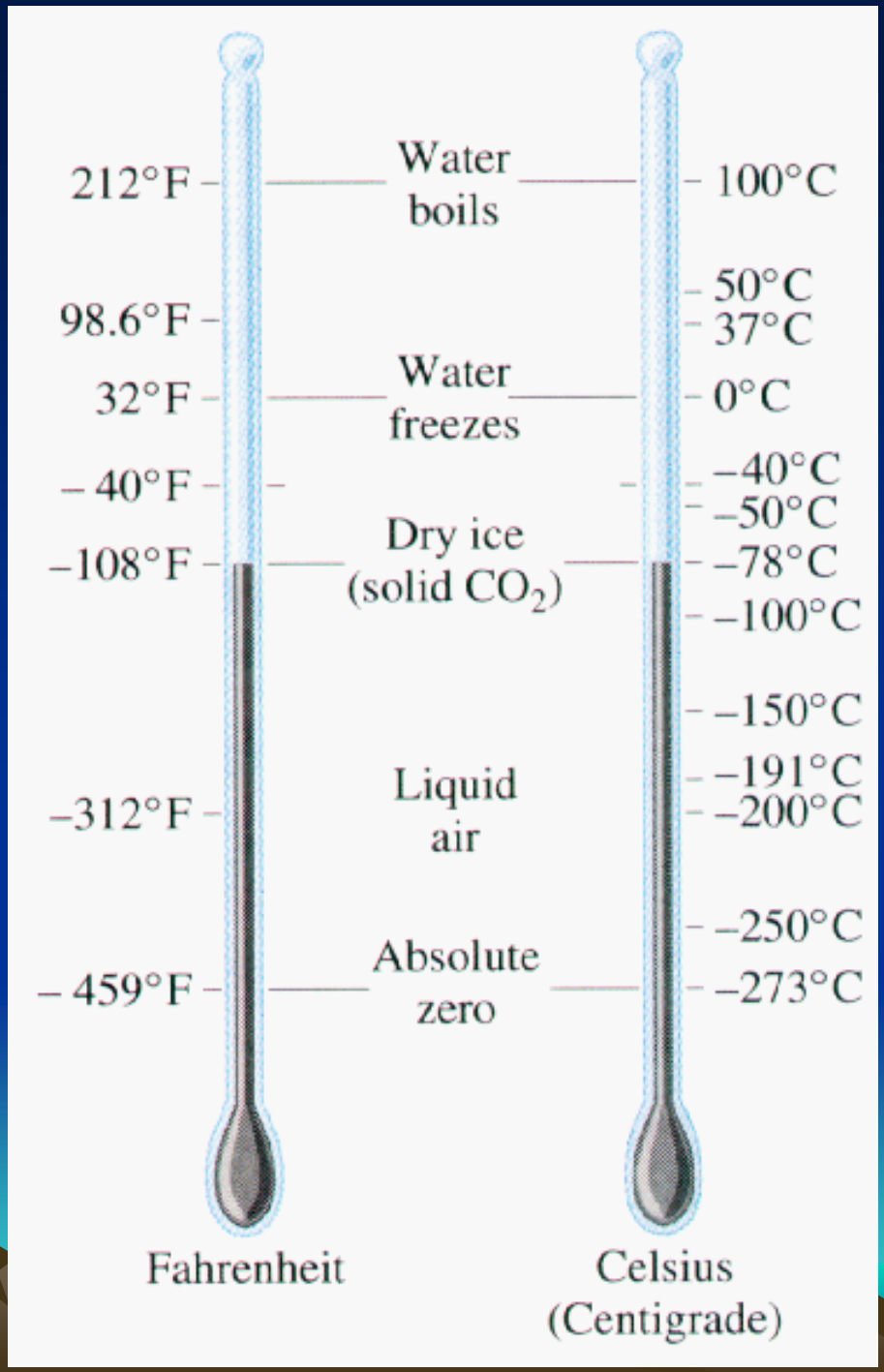


A circular arrangement of gamma detector array allows reconstruction of a thin slice of PET image

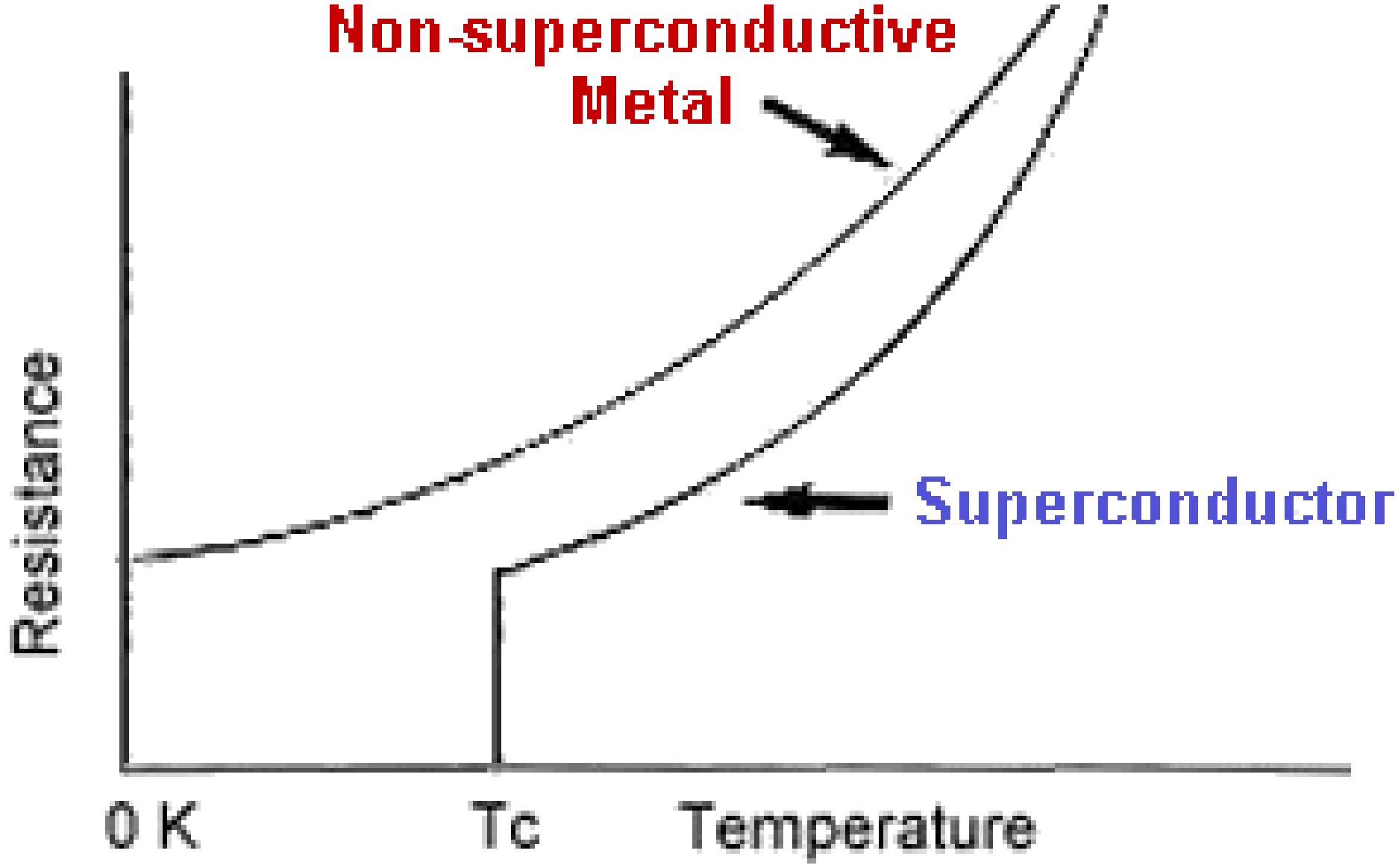
Colder



How to understand the “extremely cold-world”?


212°F
Water boils
100°C
50°C
98.6°F
37°C
32°F
Water freezes
0°C
– 40°F
–40°C
–50°C
–108°F
Dry ice (solid CO_2)
–78°C
–100°C
–150°C
–312°F
Liquid air
–191°C
–200°C
–250°C
– 459°F
Absolute zero
–273°C
Fahrenheit
Celsius (Centigrade)

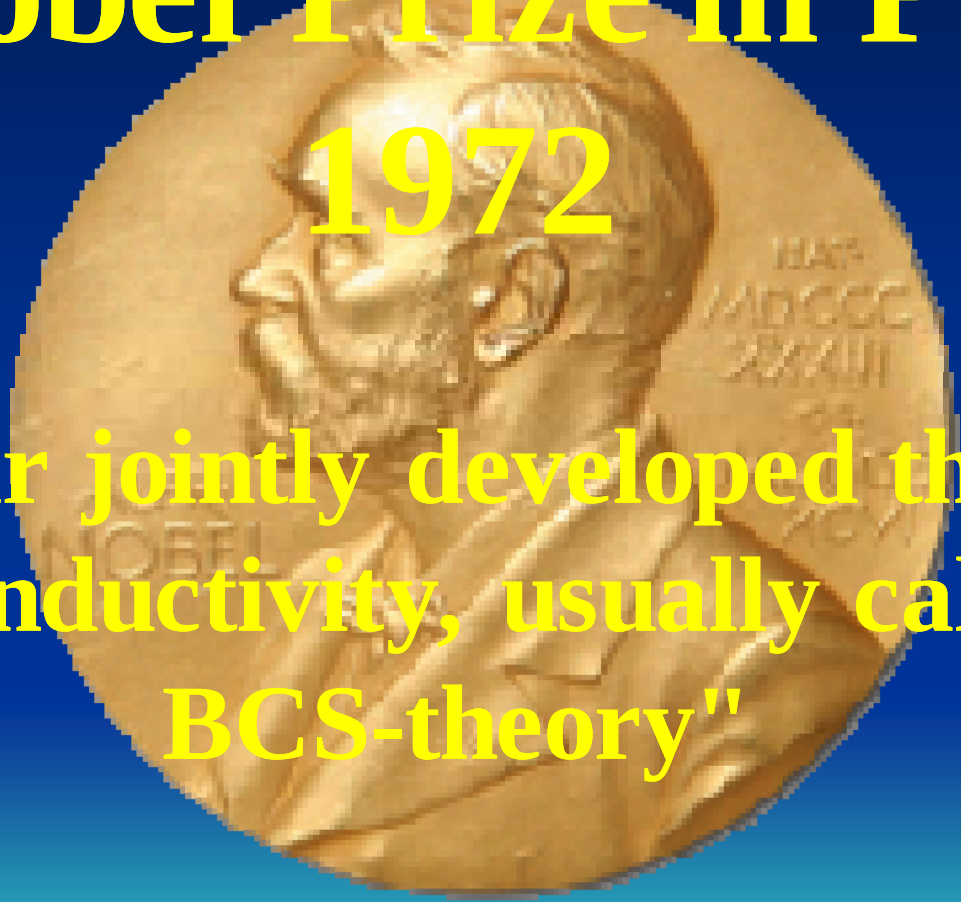
Superconductivity



Leon Cooper, John Bardeen, Robert Schrieffer

The Nobel Prize in Physics

1972



"for their jointly developed theory of superconductivity, usually called the BCS-theory"

Based on quantum mechanical principle, BCS developed a monumental theory of superconductivity

momentum operators by applying projection operators and we form an orthogonal set. For the uniform solution,

$$S_3 = i\sum_{k_z>0}(L_k\psi_k\dagger\psi_{-k}\dagger + \text{cc}).$$

Noting that the method has a variational aspect, L_k need not be taken from the small-oscillation analysis but may be freely chosen to describe average large-amplitude effects. We obtain improved ground-state energy and single- and multiple-excitation spectra.

For the solid-like solution, $f(\mathbf{x})$ is periodic. We expand $\psi = \sum a_k{}^\alpha \varphi_k{}^\alpha(\mathbf{x})$, where $[a_k{}^\alpha, a_l{}^{\dagger\beta}] = \delta_{\alpha,\beta}\delta_{k,l}$. Here $\varphi_k{}^\alpha$ are a complete set of Bloch tight-binding orbitals for which $\mathbf{k}$ takes on values in the first zone; α labels the zones. For $\mathbf{k}=0$ the $\varphi_k{}^\alpha$ are periodic; for $\mathbf{k}\neq 0$ they have a modulating factor. Thus if the linear shift is performed only for the $a_0{}^\alpha$, the ground-state expectation values of physical quantities are periodic. If shifts for $\mathbf{k}\neq 0$ are required, the expectation value of the correlation operator ceases to be periodic.

The connection between the two solutions is seen by referring to the quantum problem of a particle in a well with several minima (or stationary points). Because of the tunnel effect, good approximate wave functions are superpositions of functions appropriate to the classical separate regions. By analogy, we take

$$\Psi = \mathcal{P}(N)\mathcal{P}(\mathbf{P})\int G(R)\exp S_2(R) \cdot \exp S_3(R)\Phi(\cdots N_k\cdots)dR.$$

The coefficients of the linear and quadratic forms depend on R; the integral over R includes a discrete sum; $\mathcal{P}(N)$ and $\mathcal{P}(\mathbf{P})$ are projection operators of total number of particles N with total momentum $\mathbf{P}$. Detailed calculations of properties of liquid and solid helium based on the present approach are in progress.

[1] E. P. Gross, Phys. Rev. **100**, 1571 (1955).
[2] N. Bogolyubov, J. Phys. (U.S.S.R.) **11**, 23 (1947).

Microscopic Theory of Superconductivity*

J. Bardeen, L. N. Cooper, and J. R. Schrieffer
Department of Physics, University of Illinois, Urbana, Illinois
(Received February 18, 1957)

SINCE the discovery of the isotope effect, it has been known that superconductivity arises from the interaction between electrons and lattice vibrations, but it has proved difficult to construct an adequate theory based on this concept. As has been shown by Fröhlich,[1] and in a more complete analysis by Bardeen and Pines[2] in which Coulomb effects were included, interactions between electrons and the phonon field lead to an interaction between electrons which may be expressed in the form

$$H_I = \sum_{k,k',s,s'} \frac{\hbar\omega|M_\kappa|^2}{(E_k - E_{k'})^2 - (\hbar\omega)^2} \times c^*_{k'-\kappa,s'}c_{k',s'}c^*_{k+\kappa,s}c_{k,s} + H_{\text{Coul}}, \quad (1)$$

where $|M_\kappa|^2$ is the matrix element for the electron-phonon interaction for the phonon wave vector κ, calculated for the zero-point amplitude of the vibrations, the c's are creation and destruction operators for the electrons in the Bloch states specified by the wave vector $\mathbf{k}$ and spin s, and H_{Coul} represents the screened Coulomb interaction.

Early attempts[3] to construct a theory were based essentially on the self-energy of the electrons, although it was recognized that a true interaction between electrons probably played an essential role. These theories gave the isotope effect, but contained various difficulties, one of which was that the calculated energy difference between what was thought to represent normal and superconducting states was far too large. It is now believed that the self-energy occurs in the normal state, and results in a slight shift of the energies of the Bloch states and a renormalization of the matrix elements.

The present theory is based on the fact that the phonon interaction is negative for $|E_k - E_{k'}| < \hbar\omega$. We believe that the criterion for superconductivity is essentially that this negative interaction dominate over the matrix element of the Coulomb interaction, which for free electrons in a volume Ω is $2\pi e^2/\Omega\kappa^2$. In the Bohm-Pines[4] theory, the minimum value of κ is κ_c, somewhat less than the radius of the Fermi surface. This criterion may be expressed in the form

$$-V = \langle -(|M_\kappa|^2/\hbar\omega) + (4\pi e^2/\Omega\kappa^2)\rangle_{\text{Av}} < 0. \quad (2)$$

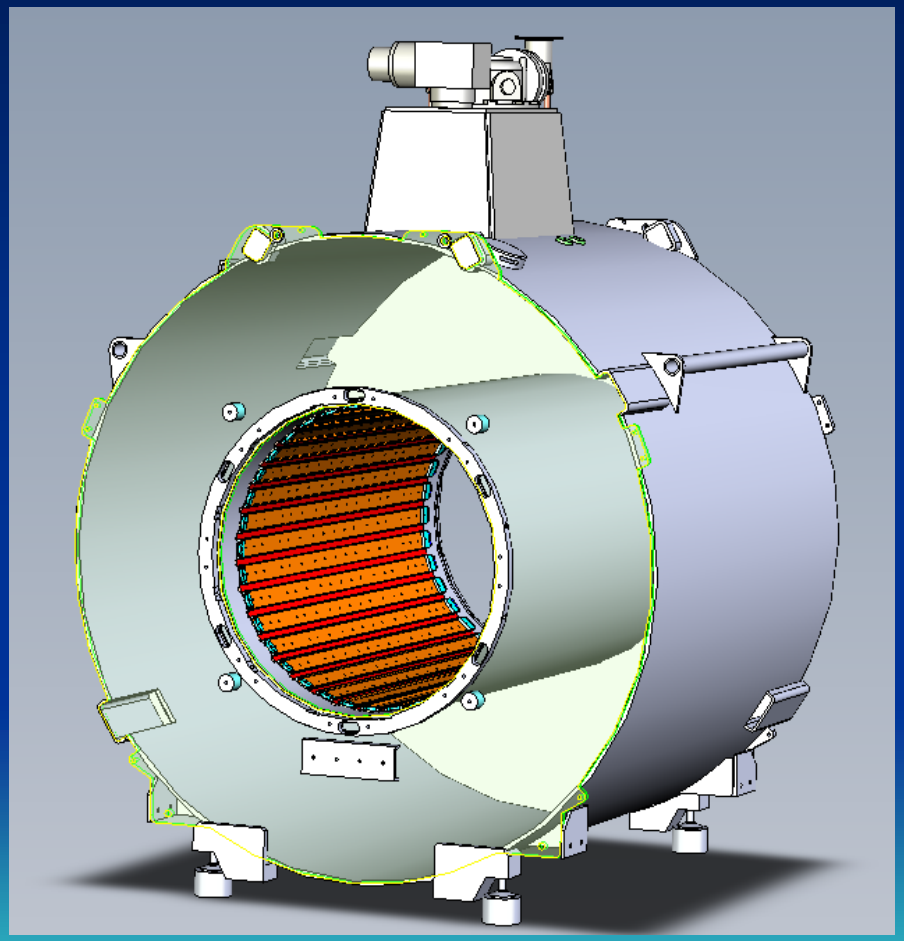
Although based on a different principle, this criterion is almost identical with the one given by Fröhlich.[1,3]

If one has a Hamiltonian matrix with predominantly negative off-diagonal matrix elements, the ground state, $\Psi = \sum \alpha_j\varphi_j$, is a linear combination of the original basic states with coefficients predominantly of one sign. A particularly simple example is one for which the original states are degenerate and each state is connected to n other states by the same matrix element $-V$. The ground state, a sum of the original set with equal coefficients, is lowered in energy by $-nV$. One of the authors made use of this principle to construct a wave function for a single pair of electrons excited above the Fermi surface and found that for a negative interaction a bound state is formed no matter how weak the interaction.[5]

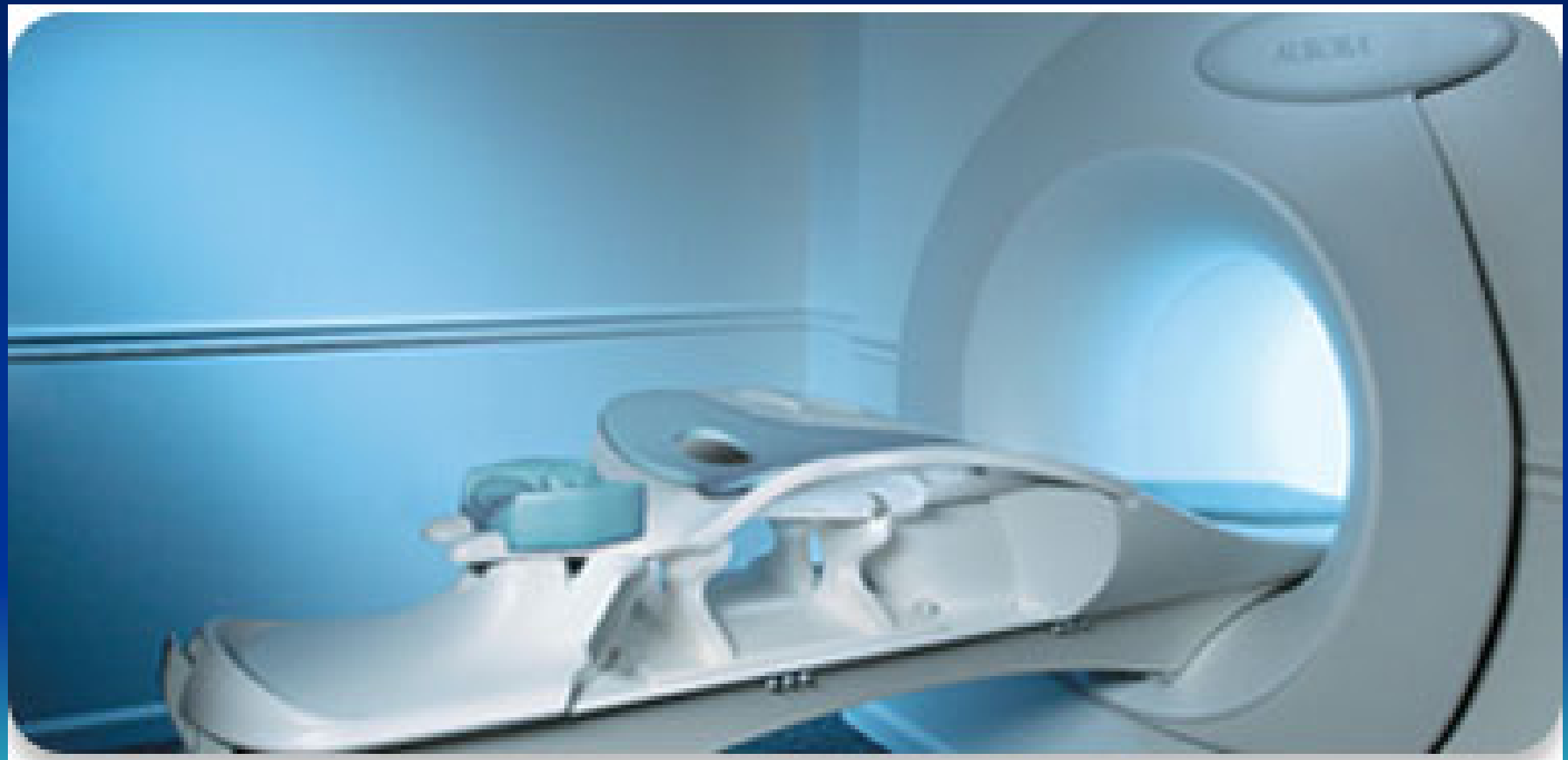
Because of the Fermi-Dirac statistics, difficulties are encountered if one tries to apply this principle directly to (1). Matrix elements of H_I between states specified by occupation numbers (Slater determinants) in general may be of either sign. We want to pick out

Super conducting magnet

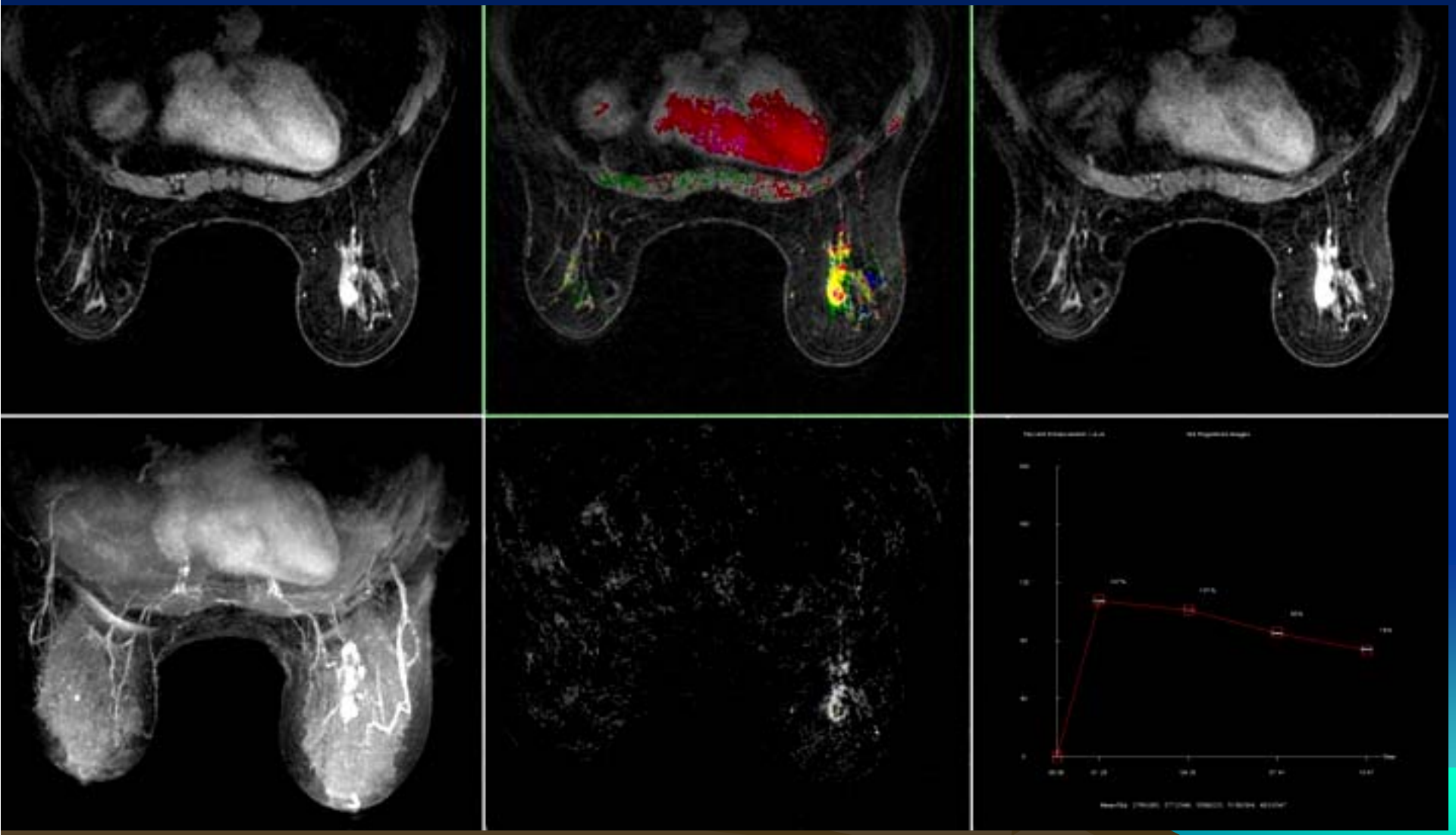
- A donut shaped vacuum vessel that houses the super conducting wire windings and the liquid helium,
- Highly homogeneous field
- High field stability,
- Field “shimming” is required in multiple stages,
- Strips on the bore are shim rails

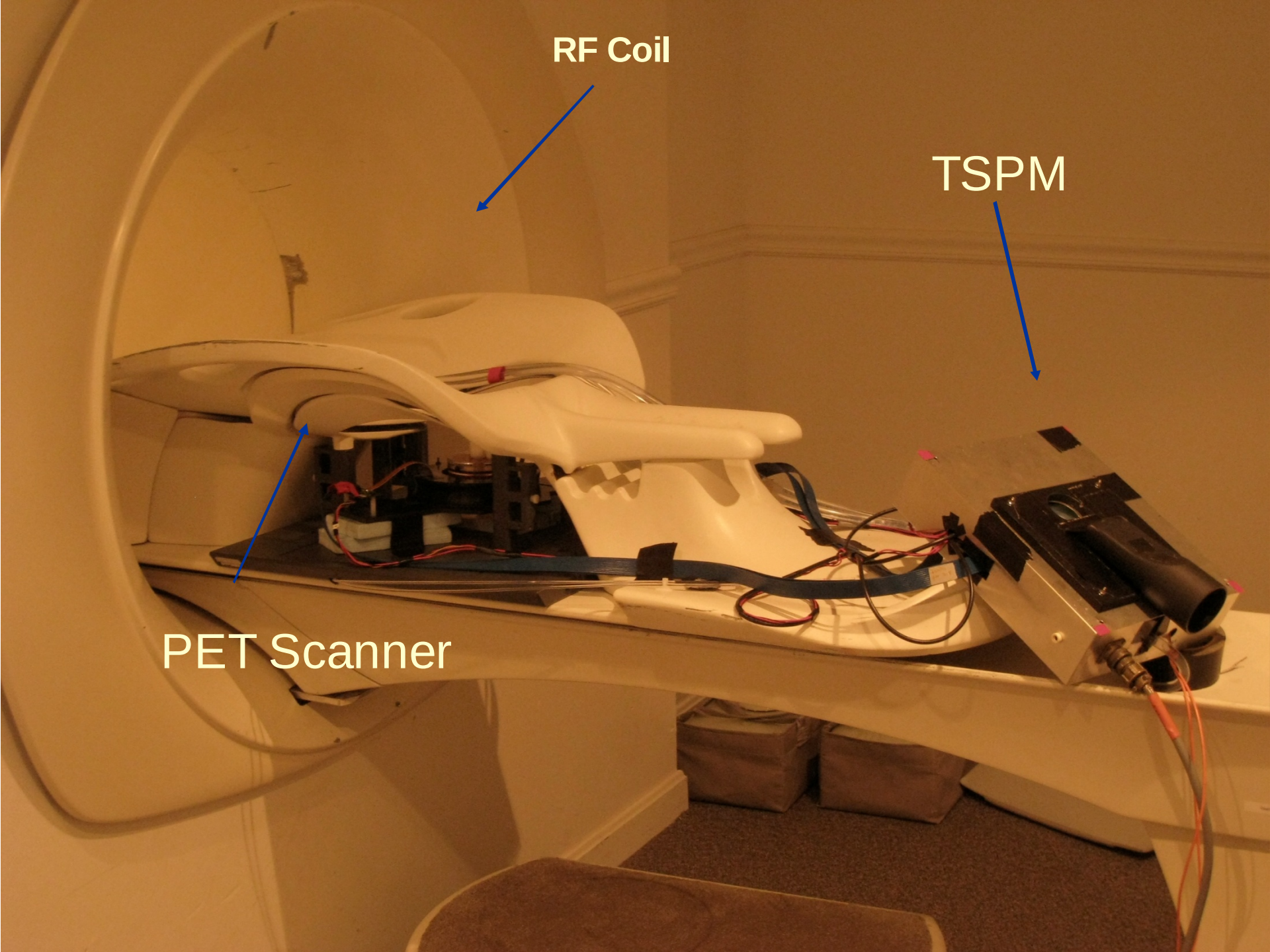


Aurora dedicated Breast Imaging MRI



Breast MRI CAD display




RF Coil
TSPM
PET Scanner

June 10, 2009

Prototype Breast Cancer Imaging System May Improve Patient Care

Custom-built breast PET-MRI system could improve accuracy of breast cancer imaging, say researchers at SNM's 56th Annual Meeting

TORONTO—A prototype breast imaging system combining positron emission tomography (PET) and magnetic resonance imaging (MRI) technologies could greatly improve breast cancer imaging capabilities, according to researchers at SNM's 56th Annual Meeting. Although the system has not yet been tested on humans, initial results from the prototype indicate the system produces a fusion of detailed PET and MRI images that should allow a more accurate classification of lesions in the breast.

"PET and MRI systems are both powerful, noninvasive tools for detecting breast cancer and evaluating treatment, but each of them also has weaknesses," said Bosky Ravindranath, research assistant working with Dr. David Schlyer at Brookhaven National Laboratory, Upton, N.Y., and lead author of a study on preliminary testing of the prototype. "We believe that combining PET and MRI in a single system will eventually yield highly sensitive and specific breast cancer examinations while at the same time compensating for the shortcomings that exist when using only PET or only MRI."


Faster
communications

20th century: Electronics

21st century: Infotronics

Spanish Flu (1918–1920)

Infotronics

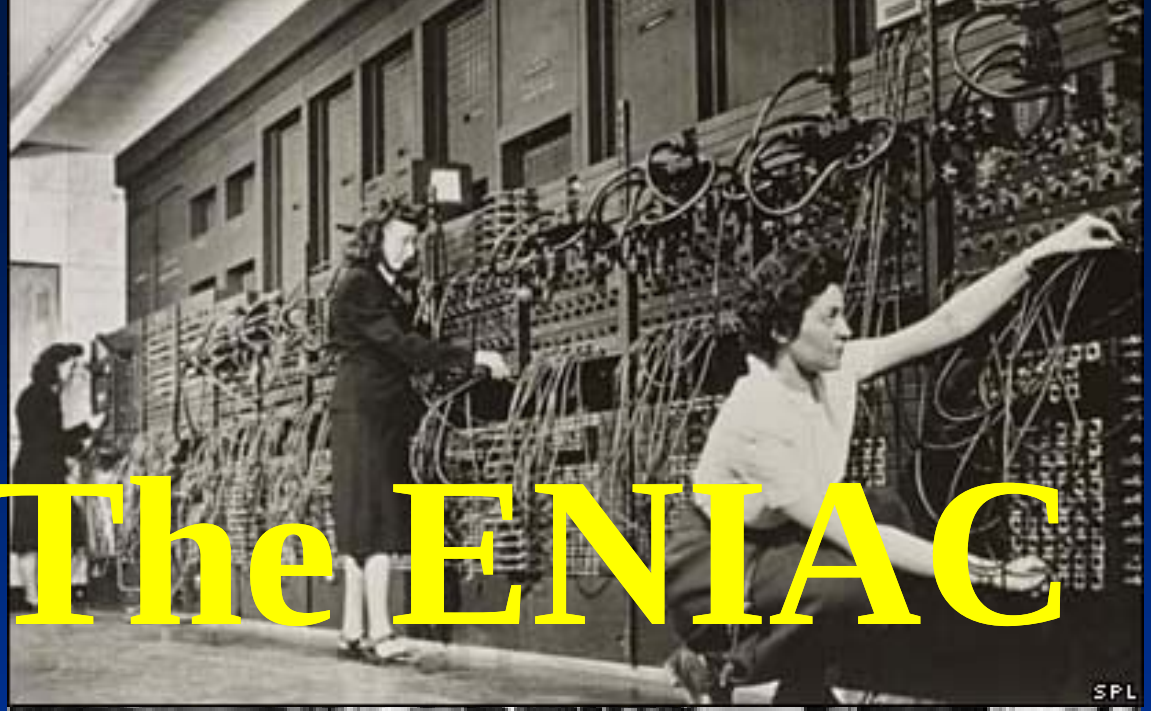
Computing

Networking

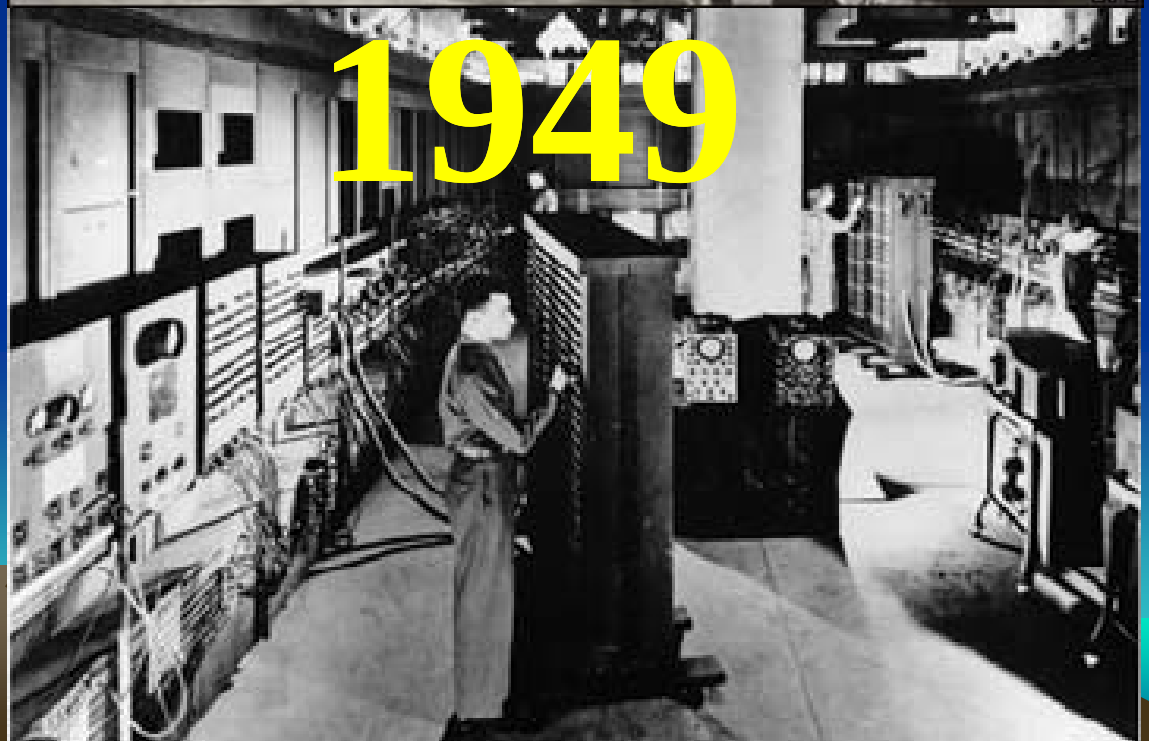
Storage

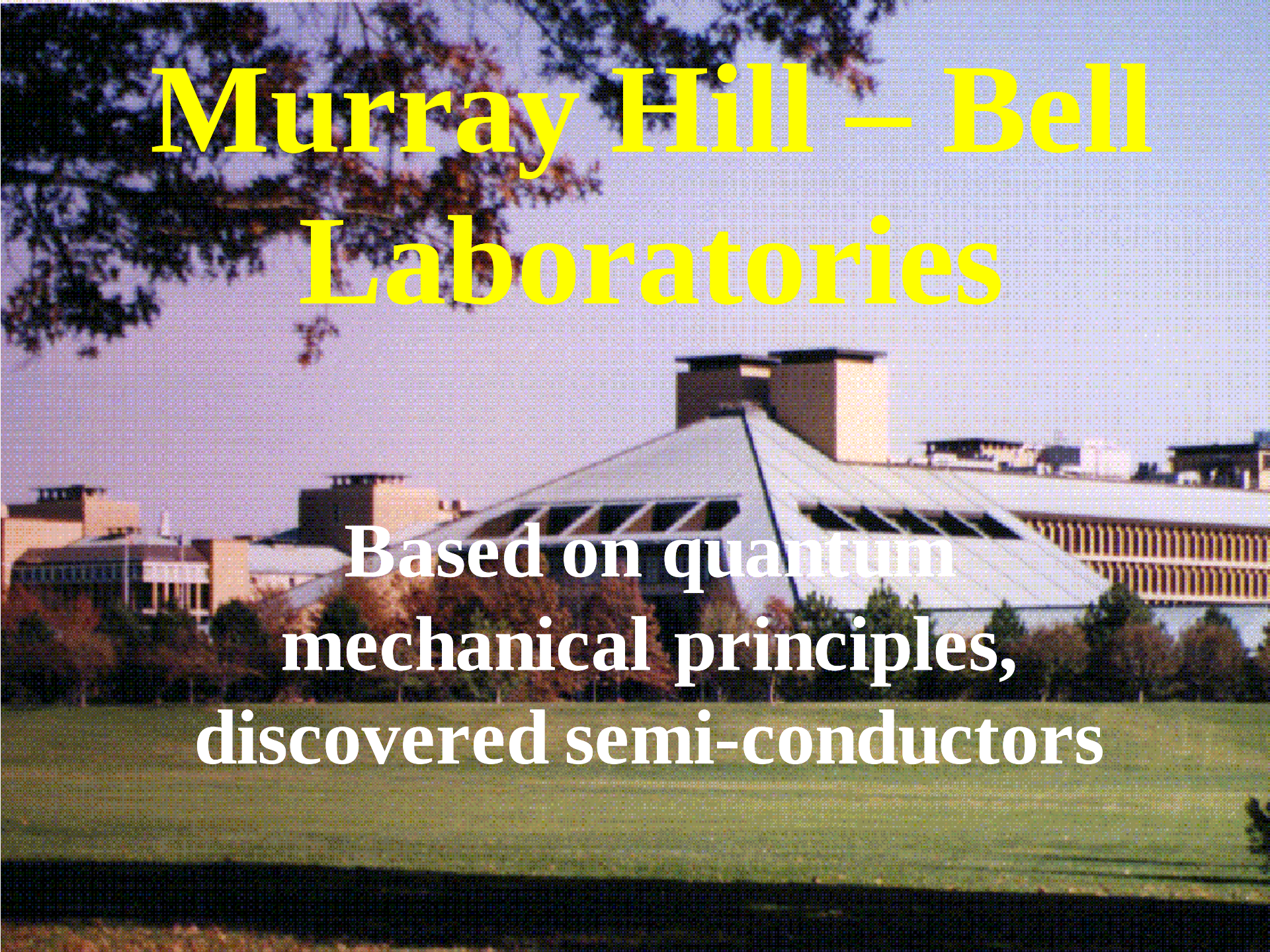
Inventors of the Computer – John Mauchly and Presper Eckert (based on vacuum tube technology)

The ENIAC



1949




Murray Hill – Bell Laboratories
Based on quantum mechanical principles, discovered semi-conductors

William Shockley, John Bardeen, Walter Houser Brattain

The Nobel Prize in Physics 1956

"for their researches on semiconductors and their discovery of the transistor effect"

ENIAC Capabilities

- 360 floating points operations per second (FLOPS) as oppose to what computers can do today which 1 petaflop (**1 petaflop is 1,000,000,000,000,000 flops**)
- 3000 bytes (as oppose to today's petabytes which is **1,000,000,000,000,000 bytes**)

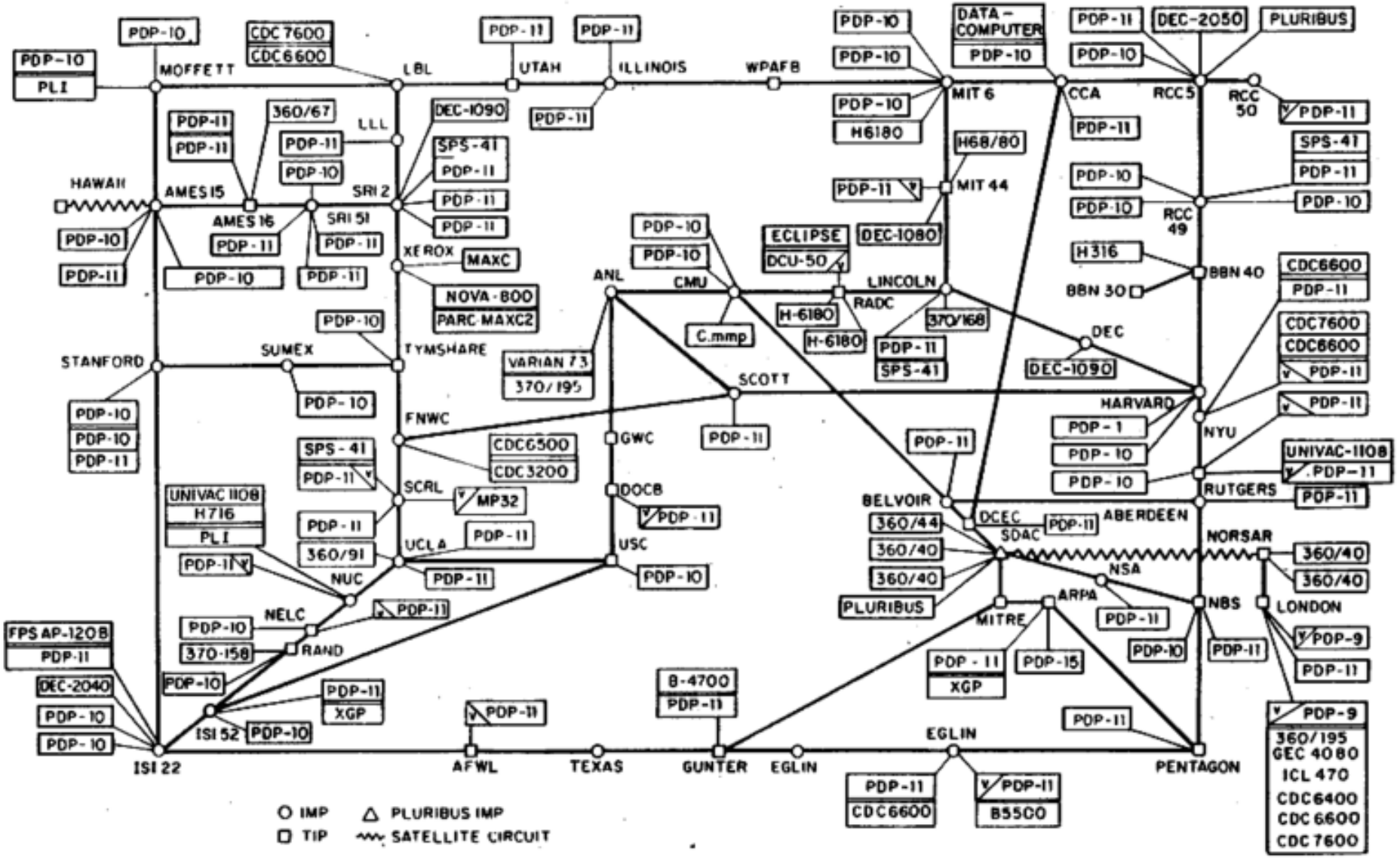
Computers with semi-conductor chips

- 1954 IBM704 12K flops 32KBytes
- 1976 Cray-1 50M flops 8MBytes
- 1991 Intel-P 10G glops
- 2009 天河 1.2P flops

Network

- **Modem** **14.4 Kbits/s**
- **T1** **1.5 Mbits/s**
- **OC12** **622 Mbits/s**
- **OC48** **2.5 Gbits/s**
- **…..**

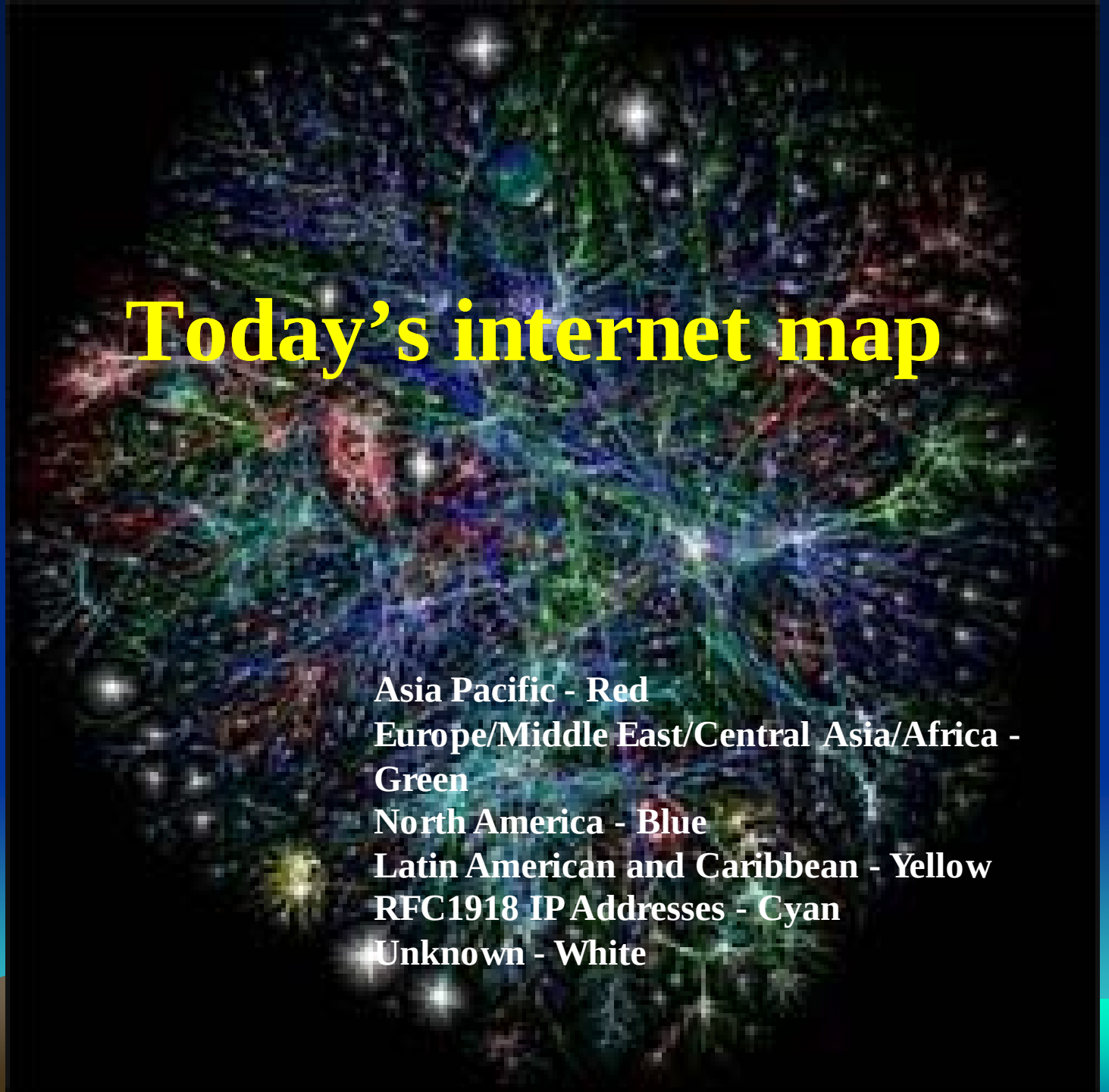
ARPANET LOGICAL MAP, MARCH 1977



(PLEASE NOTE THAT WHILE THIS MAP SHOWS THE HOST POPULATION OF THE NETWORK ACCORDING TO THE BEST INFORMATION OBTAINABLE, NO CLAIM CAN BE MADE FOR ITS ACCURACY)

NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

Today’s internet map



Asia Pacific - Red
Europe/Middle East/Central Asia/Africa - Green
North America - Blue
Latin American and Caribbean - Yellow
RFC1918 IP Addresses - Cyan
Unknown - White

Data Storage

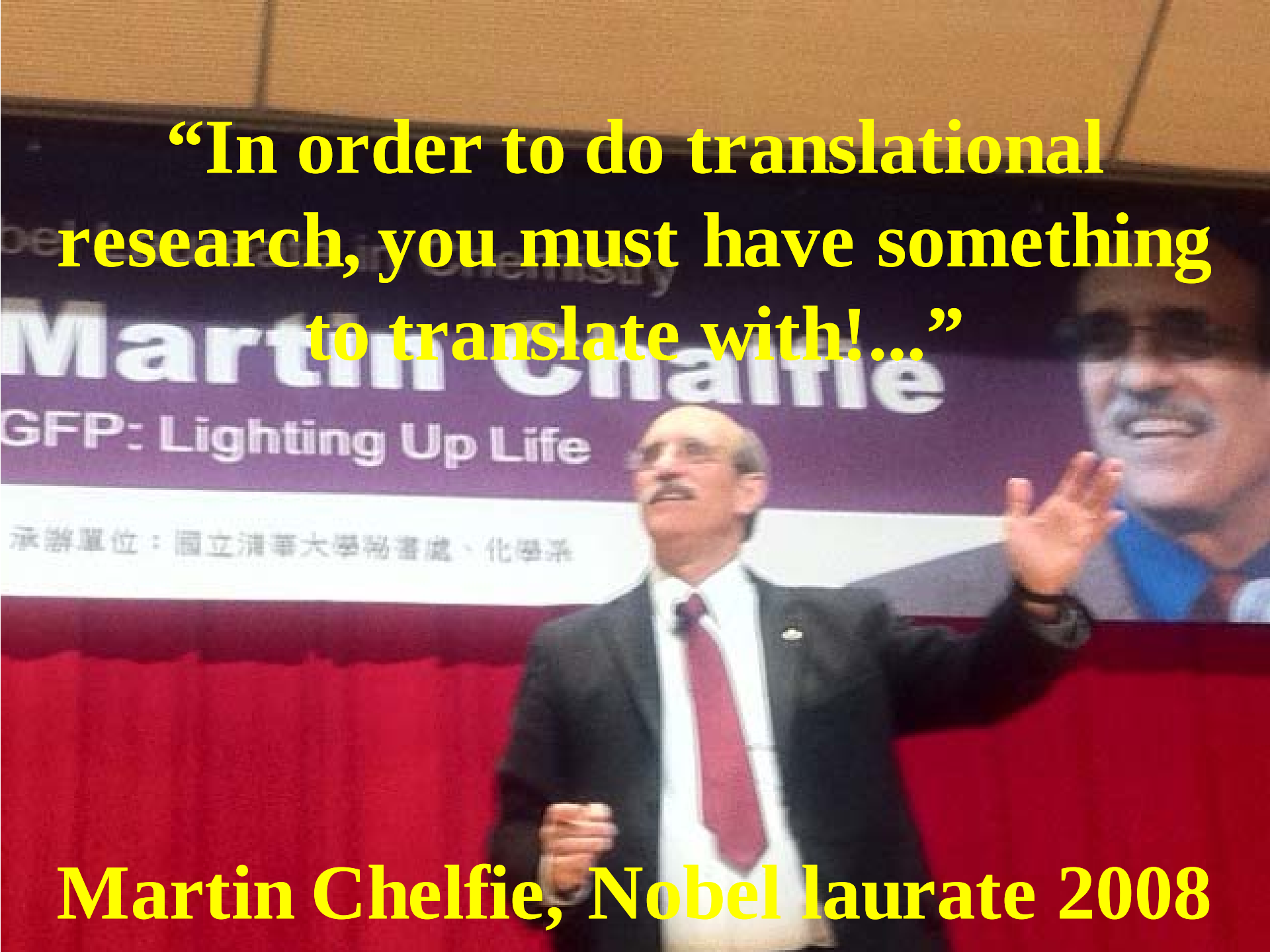
- Standard Floppy diskette 1.44Mb
- Iomega Zip disk 100Mb
- Standard CD-ROM 600Mb
- 2 GB Disk 2Gb
- Pittsburgh Supercomputing Center 200 Tb
- Petabytes

Applications of Infotronics

- **Data mining**
- **Telemedicine (health monitoring and disease prevention) and bringing high quality medical care and treatment "virtually"**
- **Real-time accurate information transformation in triage and crisis mode: New age of infectious diseases control and mitigation**

What is the lesson here?

No basic science (quantum mechanics,) none of the technological (translational) advances in the 20th century would not happen!

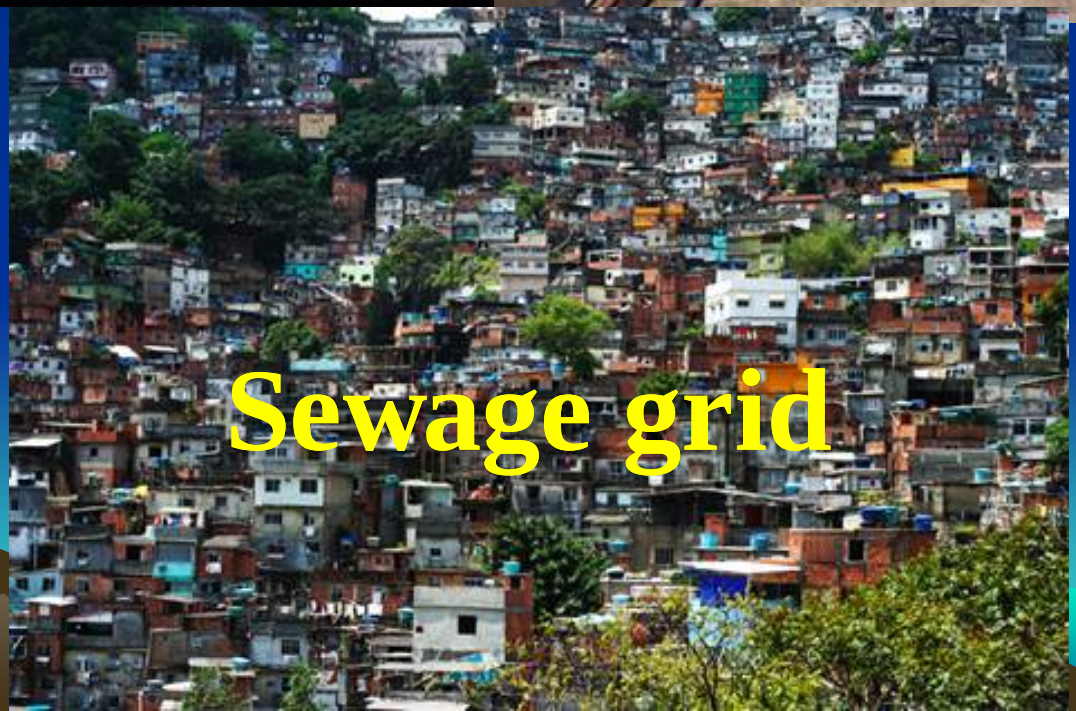

“In order to do translational research, you must have something to translate with!...”
Martin Chalfie
GFP: Lighting Up Life
Martin Chelfie, Nobel laurate 2008

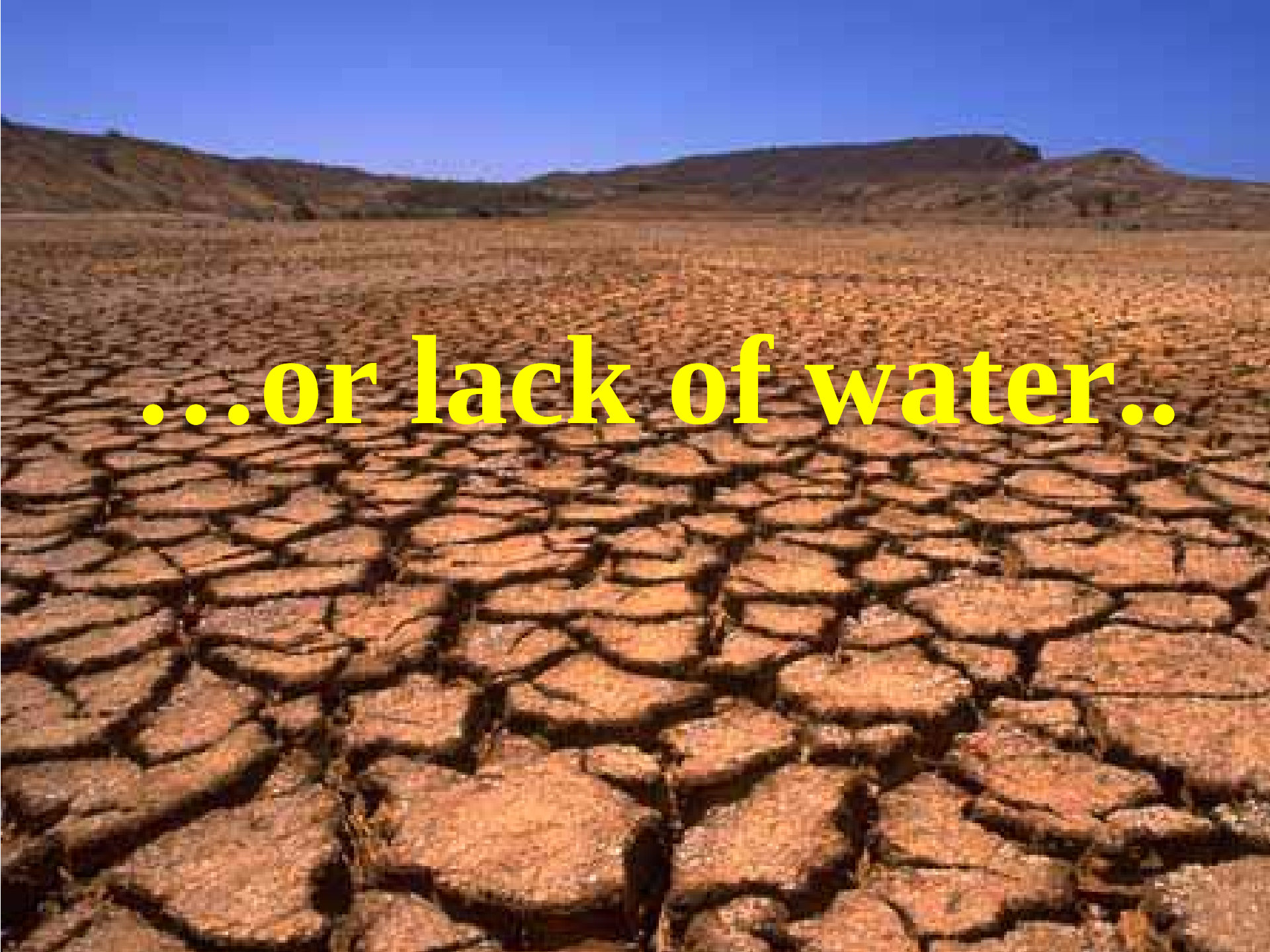
What about the 21st century?

Problems such as a large percentage of human population does not have the three fundamental grids of modern living…


Electric grid


Water grid

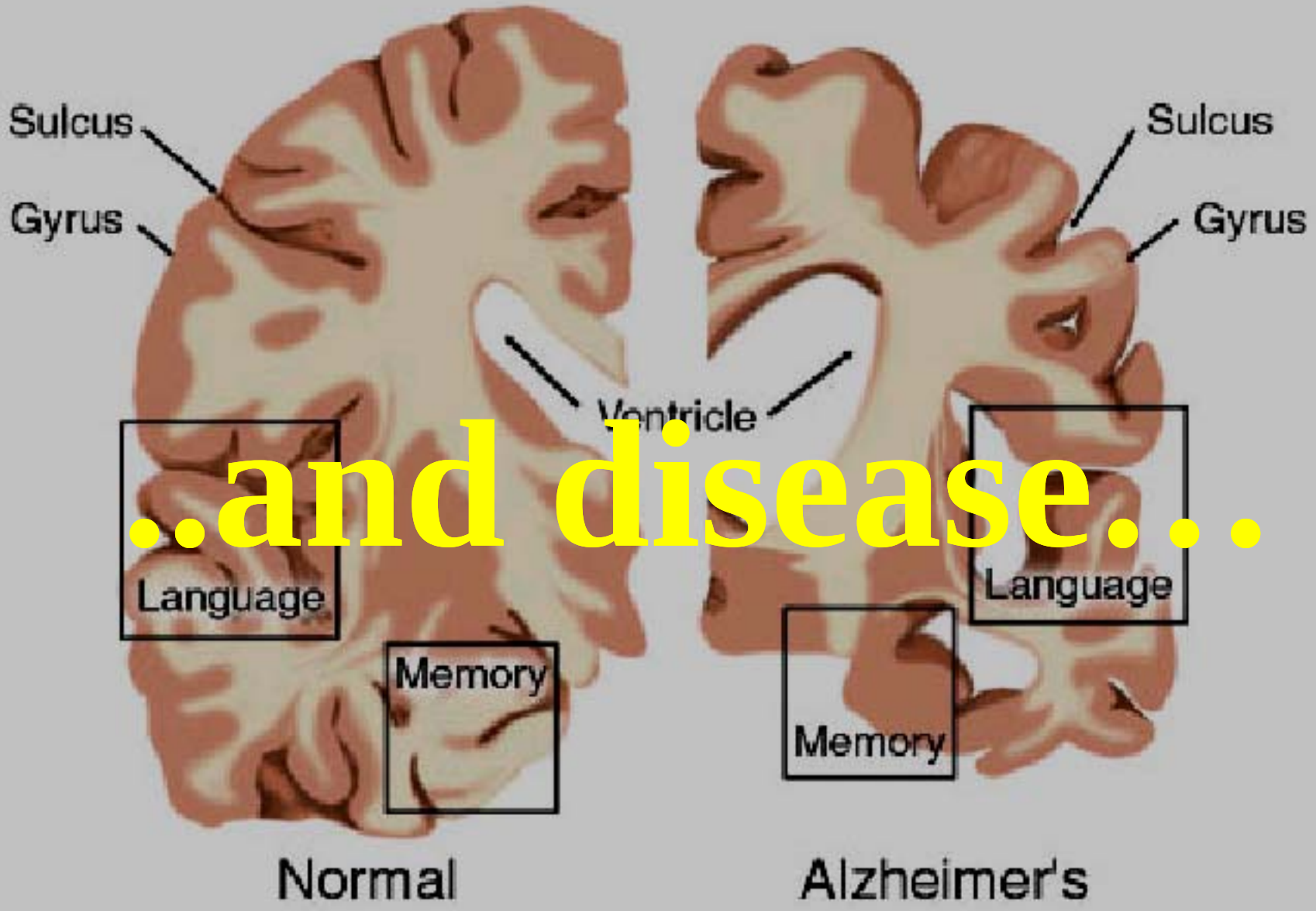

Sewage grid


…or lack of water..


..or lack of energy


..Global warming…


..and poverty and ignorance..


Sulcus
Gyrus
Sulcus
Gyrus
Ventricle
Language
Memory
Memory
Language
Normal
Alzheimer's

..and disease…

…and human hatred…

To tools to solve these Globally challenging problems are not just dependent on basic science and technology, which they must, but also in understanding human behaviors, public policies and political courage.

Recognition of the fundamental importance of public policy of the development of knowledge!

NUS
National University of Singapore

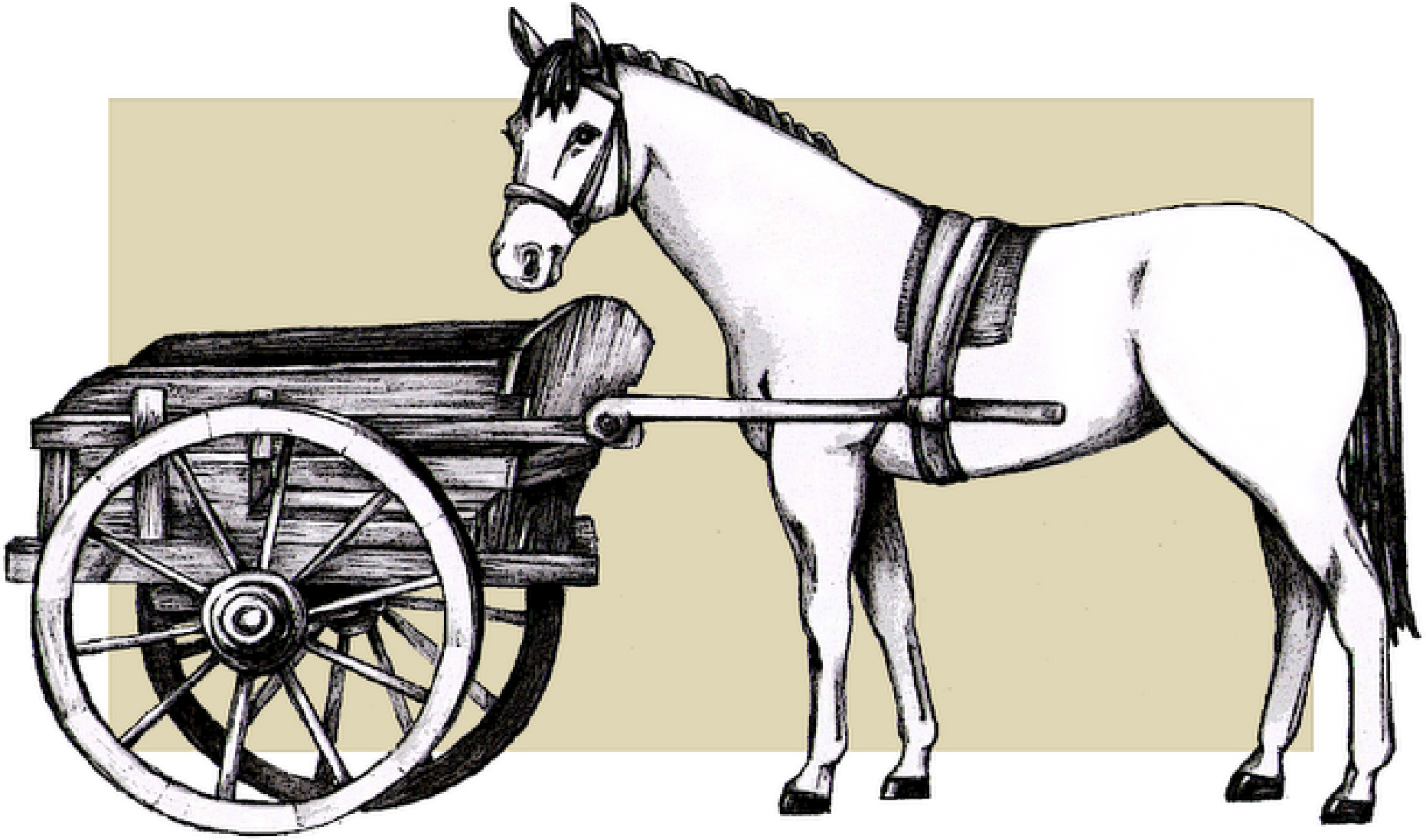
Lee Kuan Yew School of Public Policy

李嘉誠基金會
LI KA SHING
foundation
education · medical
· culture · welfare

"As a discipline it seeks to offer answers to fundamental questions such as how best to mobilize and allocate public resources, organize and coordinate public organizations, formulate and implement effective public policies, and provide quality public services."

Dr. Xue Lan (薛澜)
Dean of the School of Public Policy and Management of Tsinghua University (Beijing)

Science and technology without public policies is….



Charles Dickens

1812 - 1870

A Tale of Two Cities

“It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, we were all going direct to Heaven, we were all going direct the other way--in short, the period was so far like the present period, that some of its noisiest authorities insisted on its being received, for good or for evil, in the superlative degree of comparison only.”

Thank you Mr. Dickens for writing about our era in such vivid terms!