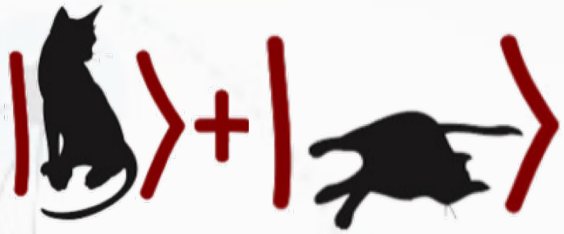
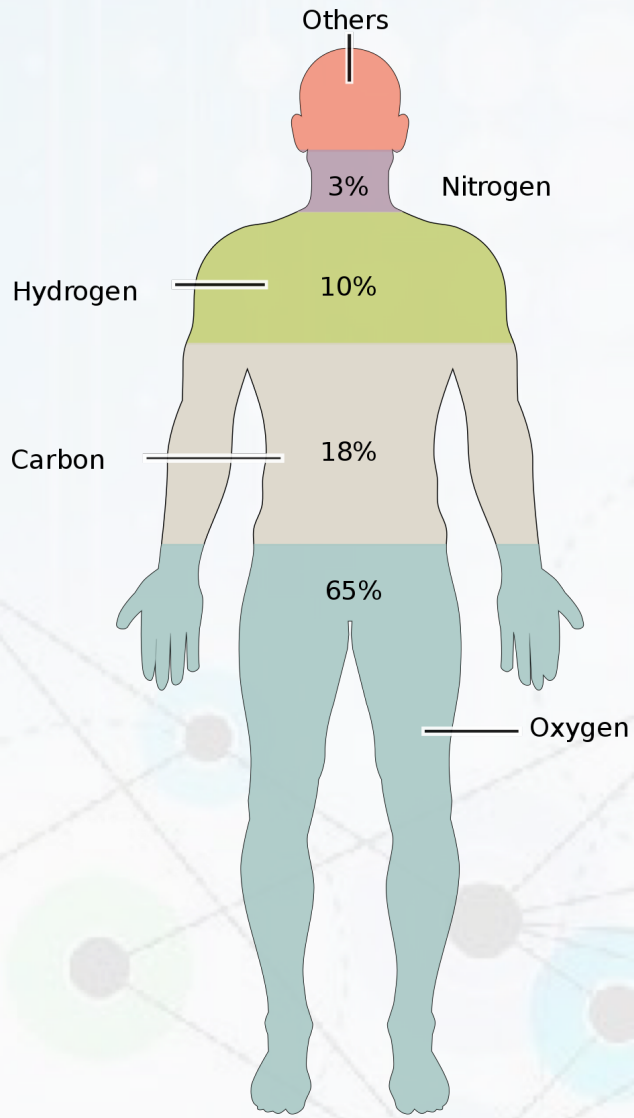
QUANTUM INFORMATION SCIENCE

How 100-year old concepts
+ Today's state-of-the-art technology
= Future advances in computing, sensing, communications …

"About your cat, Mr. Schrödinger—I have good news and bad news."

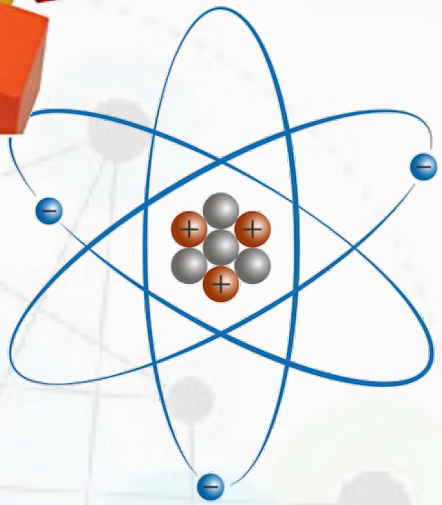


WHAT WE ARE MADE OF



7,000,000,000,000,000,000,000,000 atoms*
= 70,000,000,000,000,000,000,000,000
protons, neutrons and electrons

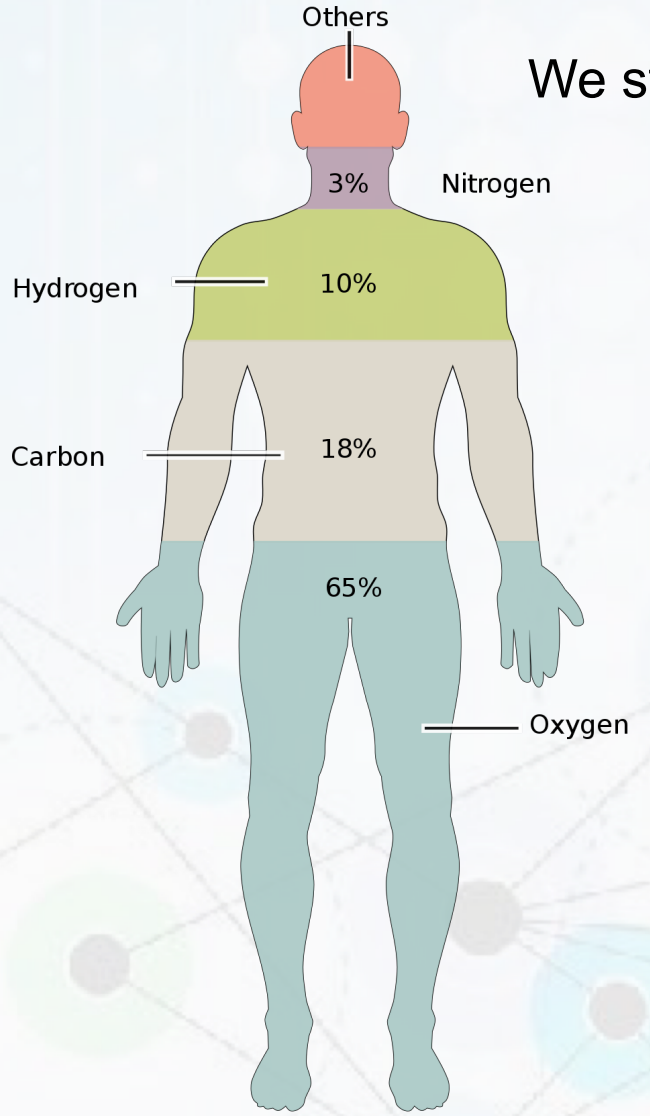
That's a lot of building blocks



Atom structure
- Proton
- Neutron
- Electron

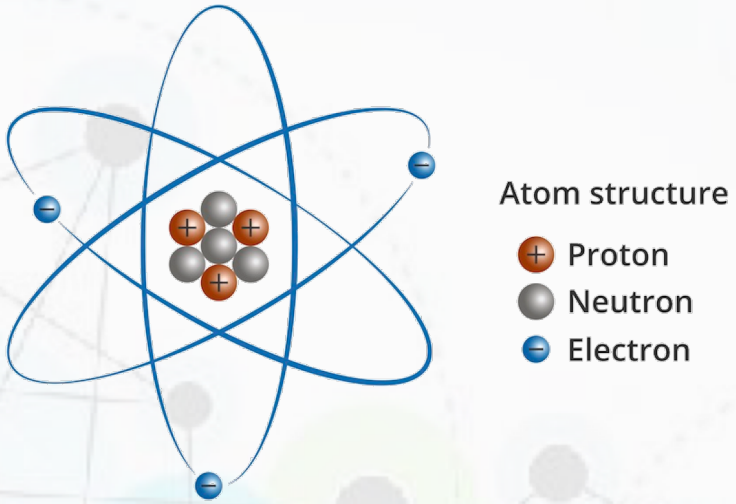
*$7x10^{27}$

ABOUT 100 YEARS AGO



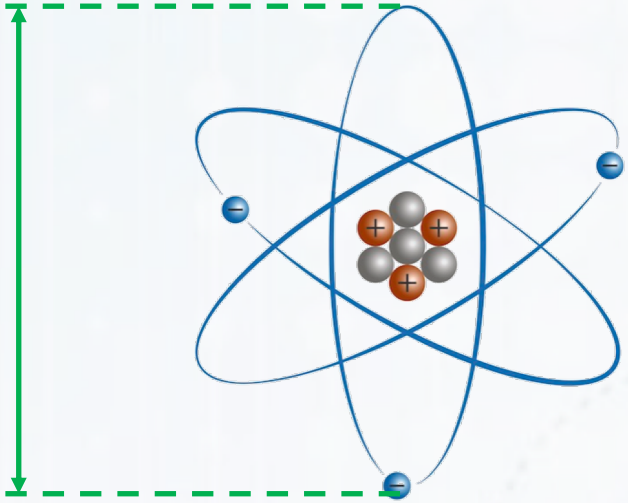
We started to understand that the rules on this scale

Are *not* the same as the rules on this scale



QUANTUM MECHANICS

Strict rules for small things



e.g. *quantization*

But counterintuitive

If quantum mechanics hasn't profoundly shocked you, you haven't understood it yet.

(Niels Bohr)

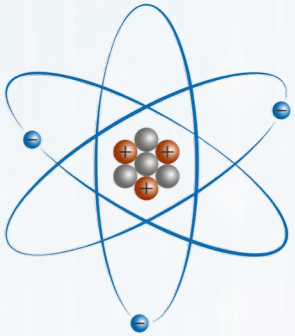
If you think you understand quantum mechanics, you don't understand quantum mechanics.

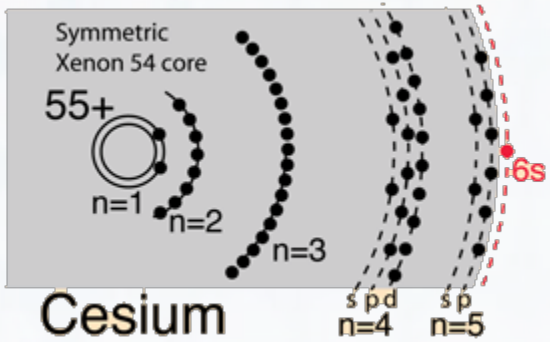
— Richard P. Feynman —

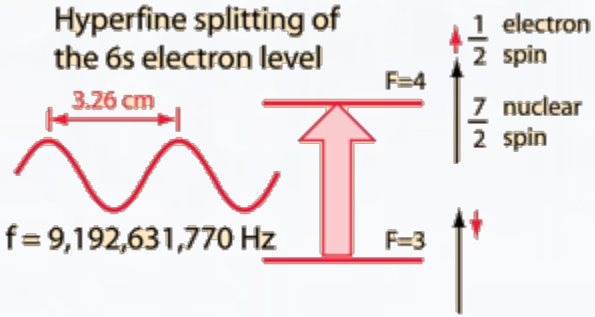
Although quantum mechanics has been around for nearly 70 years, it is still not generally understood or appreciated, even by those that use it to do calculations.

— Stephen Hawking —

QUANTUM METROLOGY: e.g. ATOMIC CLOCK







Bureau International des Poids et Mesures

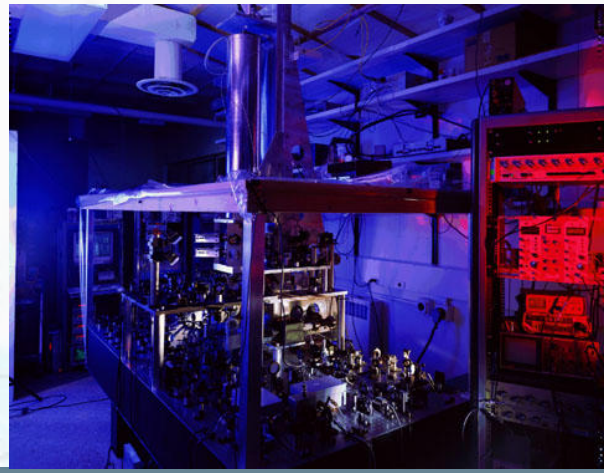
Before 1964: 1 second = 1 day / 86,400

After 1964: 1 second = 9,192,631,770 periods

of the transition between the two hyperfine levels of the unperturbed ground state of the $_{133}$Cs atom

The standard kilogram

Atomic Clock at *NIST*

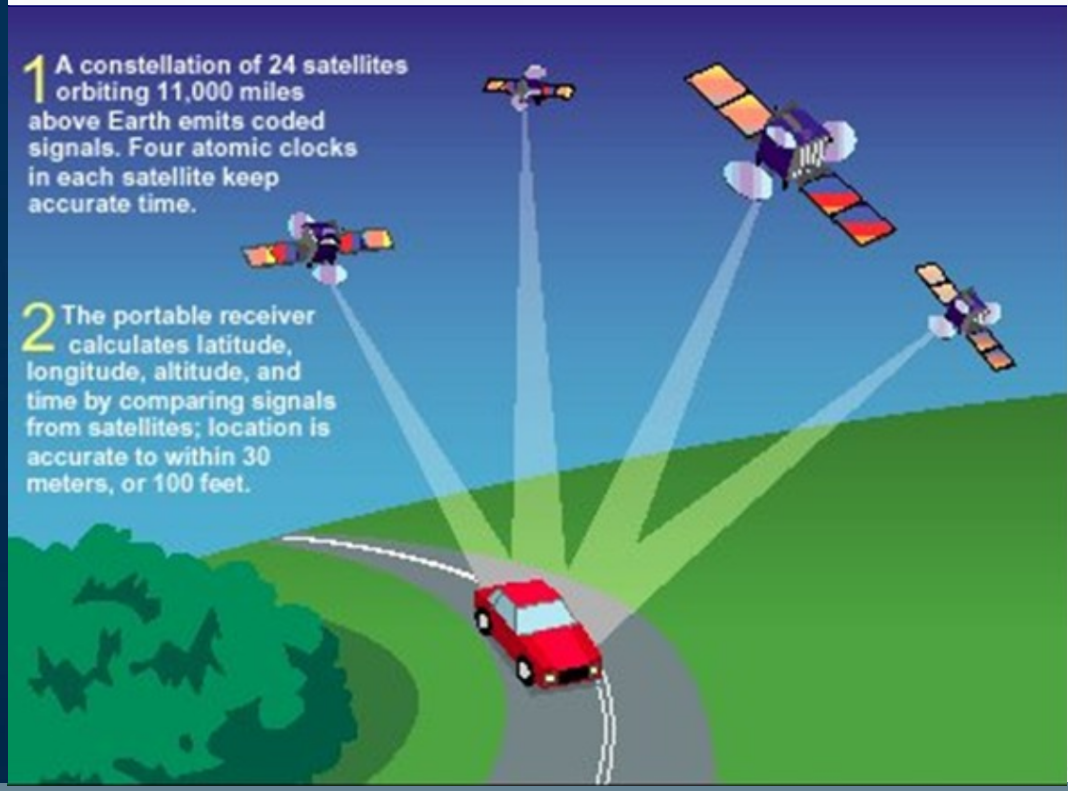


Accurate to 1 second in 300,000,000 years

EXAMPLE: GPS

The **Global Positioning System**
relies on Atomic Clocks

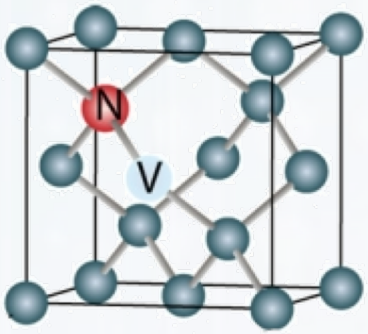
← If you use something like this, you do too!



AT BERKELEY LAB

Biology, Geology, ...

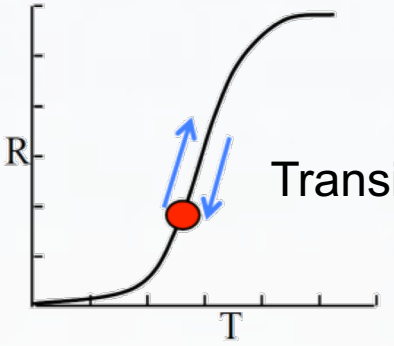
Measuring tiny magnetic fields from single cells



Nitrogen-Vacancy center in diamond

Astronomy, Cosmology, ...

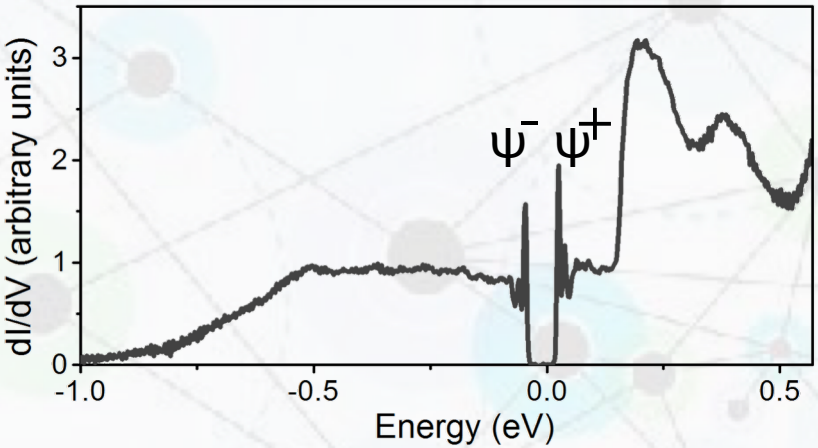
Measuring energies of “light” very precisely



Transition Edge Sensor

Materials Research

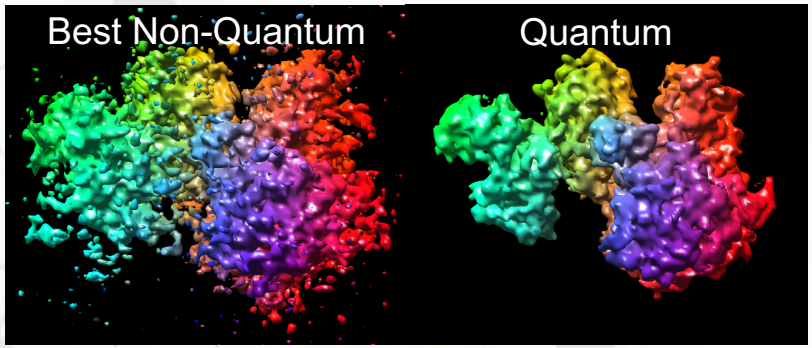
New kinds of quantum sensors



1-D Charge Density Waves in 2-D MoSe

Microscopy ...

Better ways to see small things



Quantum Electron Microscope

SUPERPOSITION

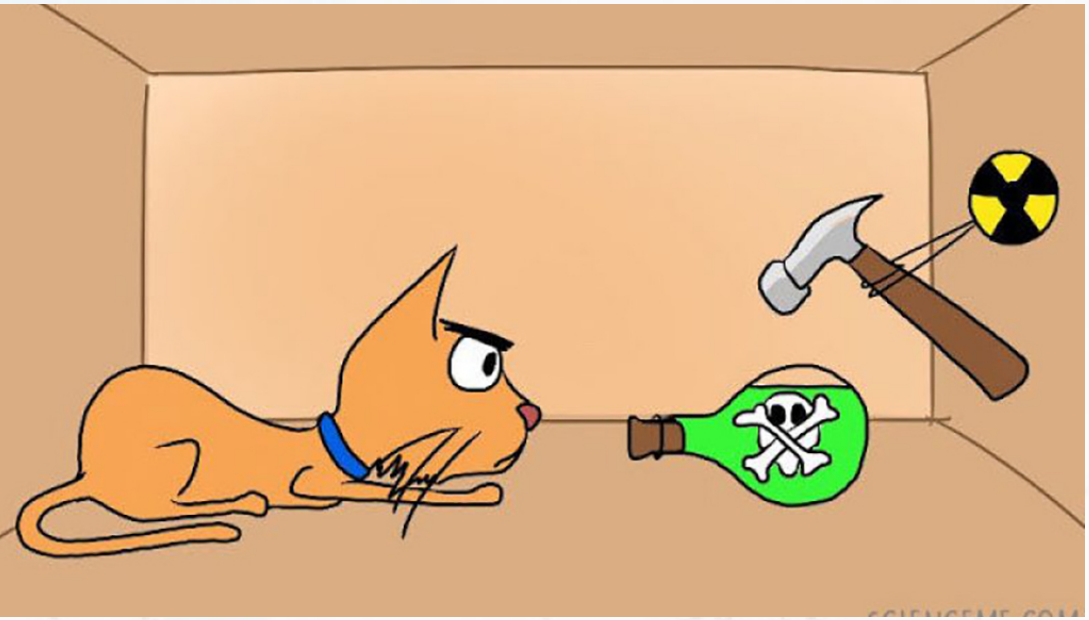
"Classical"

But once there is a *measurement*, it is either

or

“MAKING A MEASUREMENT”

Quantum objects can exist in multiple states at the same time (superposition)



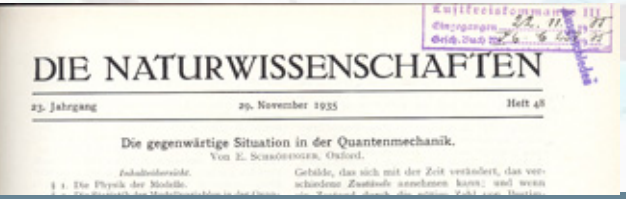
Thought experiment:
Cat in a *closed* box
Decay of one atom triggers hammer

Until we look

Cat is in a *superposition* of states

Once we look

Opening the box to observe the cat causes it to abruptly change its quantum state


DIE NATURWISSENSCHAFTEN

23. Jahrgang 29. November 1935 Heft 48

Die gegenwärtige Situation in der Quantenmechanik.

Von E. Schrödinger, Oxford.

Erwin Schrödinger - 1935

ENTANGLEMENT

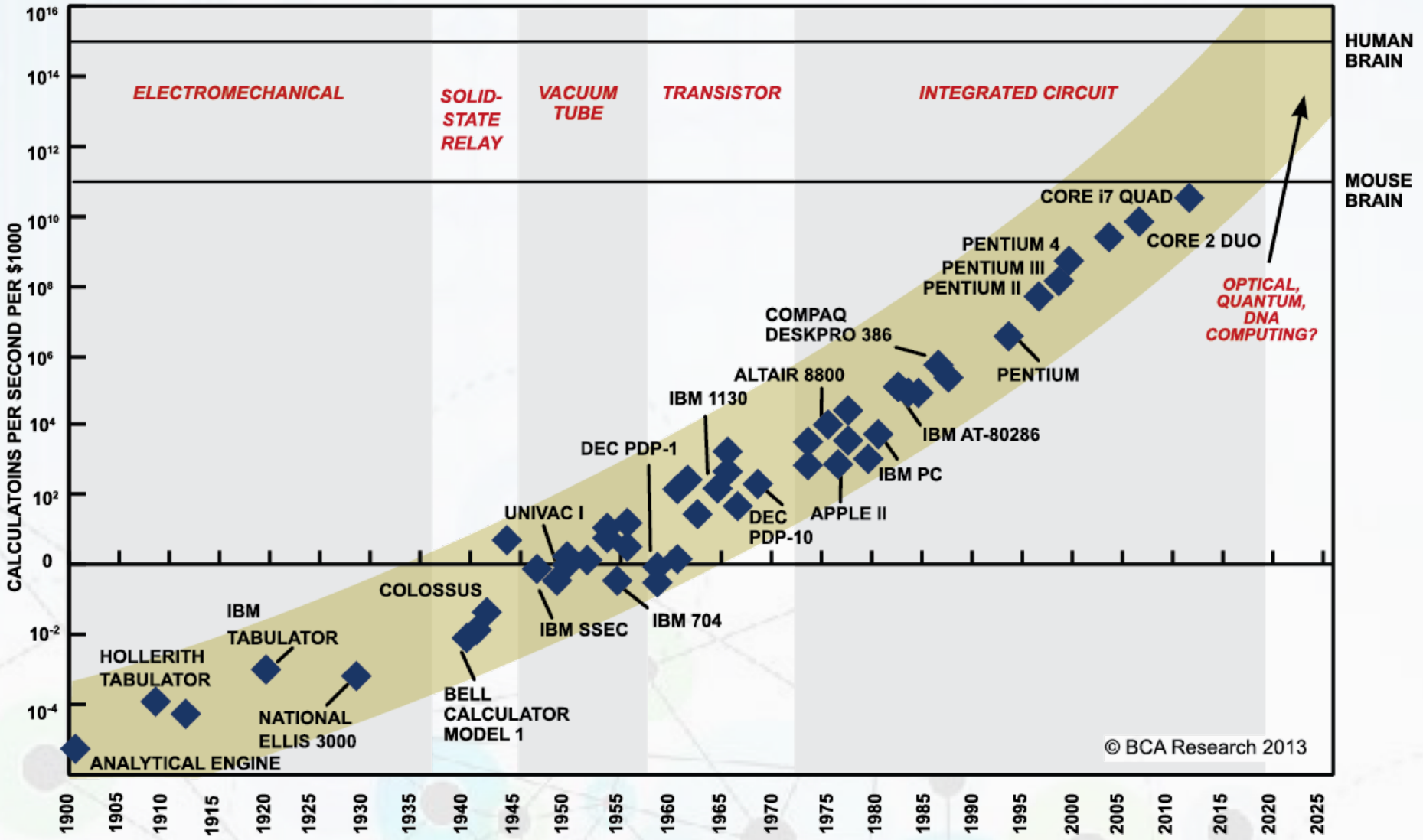
"Quantum" coin roll

- Only 2 coins
- **Must** be  and 

Flip 

If flip is 

COMPUTATION



SOURCE: RAY KURZWEIL, "THE SINGULARITY IS NEAR: WHEN HUMANS TRANSCEND BIOLOGY", P.67, *THE VIKING PRESS*, 2006. DATAPOINTS BETWEEN 2000 AND 2012 REPRESENT BCA ESTIMATES.

QUANTUM LOGIC

Classical

A *bit* is  or 

(can only be in one of two states)

Simplest logic gate: *inverter*

IN	OUT
	
	

A *bit* is **0** or **1**

Quantum

A *qubit* is **a x**  **+ b x** 

$a^2 + b^2 = 1$

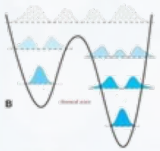
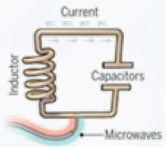
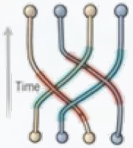
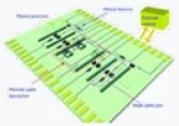
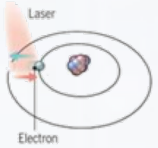
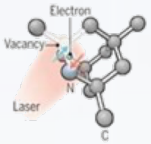
(can only be in one of many states)

Simplest logic gate: *inverter*

IN	**a**  **+ b** 
OUT	**a**  **+ b** 

A *qubit* is **a x 0 + b x 1**

WHAT'S THE BEST QUBIT?

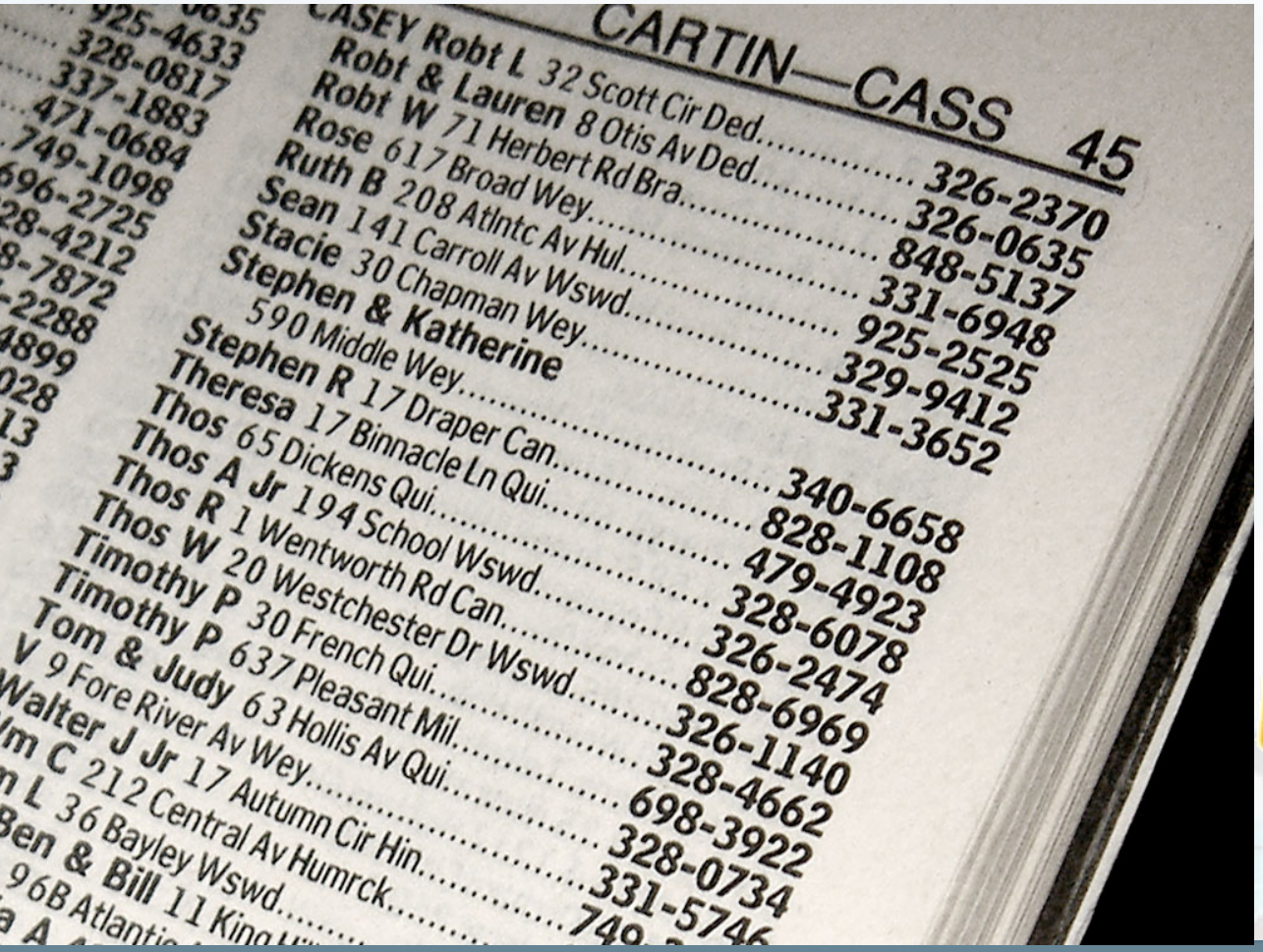
	 recuit quantique	 boucles supra-conductrices	 qubits topologiques	 optique linéaire	 quantum dots silicium	 ions piégés	 cavités diamants
qubit	supraconducteur effet Josephson	supraconducteur effet Josephson	quasi-particules faites de paires d'anyons	photons	spin d'électrons dans semi-conducteur	ions piégés magnétiquement	spin de noyau d'atomes
# qubit	**2048 qubits** (D-Wave)	**50 qubits** (IBM) **72 qubits** (Google)	**N/A**	**quelques-uns**	**49 qubits** (Intel)	**53 qubits** (IonQ) **51 qubits** (MIT) **20 qubits** (IQOQI)	**6 qubits** (QDTI)
état	sens du courant	phase de résonnance ou sens du courant	sens de l'anyon	phase de photon	spins d'électrons	niveau énergétique de l'ion piégé	niveau d'énergie de la cavité
portes	micro-ondes 5 GHz et effet Josephson	micro-ondes 5 GHz et effet Josephson	inversions 2D d'anyons	filtres polarisants et dichroïques	micro-ondes	laser	laser
mesure	magnétomètre	magnétomètre	fusion d'anyons	détecteurs de photons	consersion spins to charge	fluorescence	fluorescence

https://www.oezratty.net/wordpress/2018/comprendre-informatique-quantique-qubits/

WHAT CAN YOU DO WITH IT?

For example: Grover search algorithm $\sim\sqrt{N}$, classical $\sim N$

Find the name in a phone book given the phone number

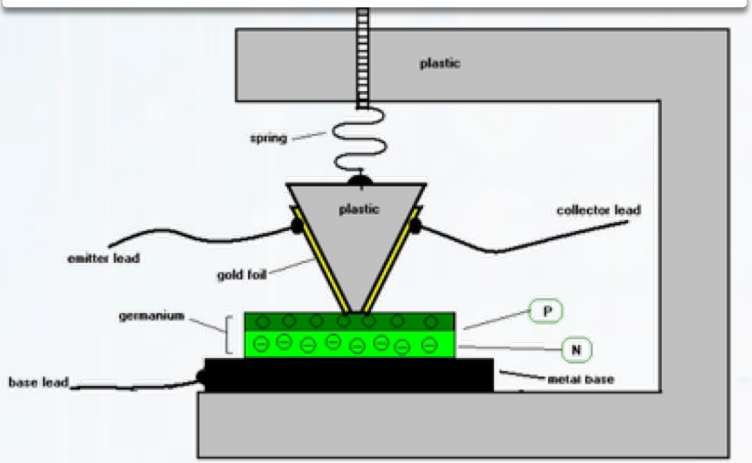


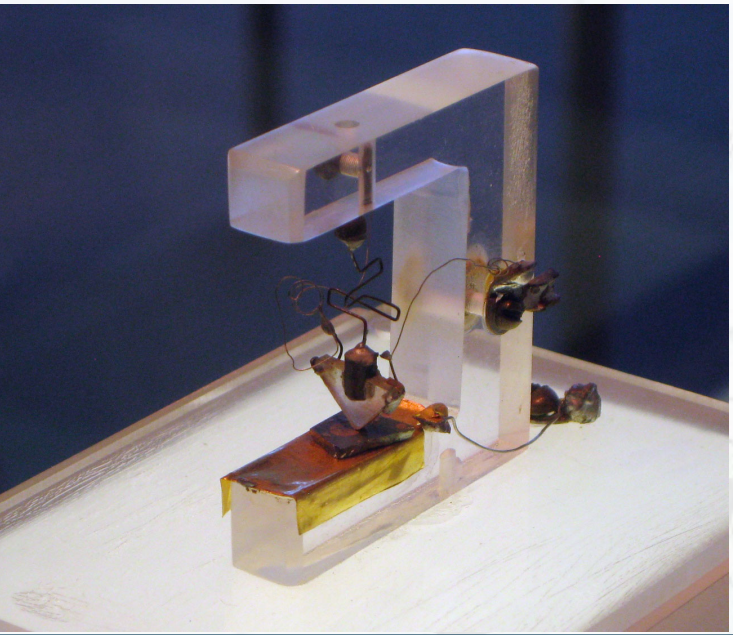
In a phone book with 10,000 entries,
Classical takes ~10,000 tries
Quantum takes ~100 tries

Ancient Database Format

IN ¼ CENTURY – 50 YEARS AGO

Point Contact Germanium Bipolar Transistor
Bell Labs 1947





Integrated Circuit
Texas Instruments 1959

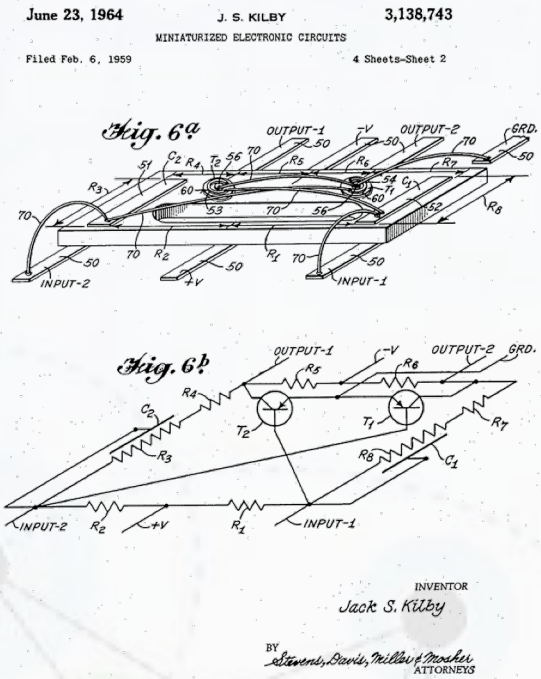
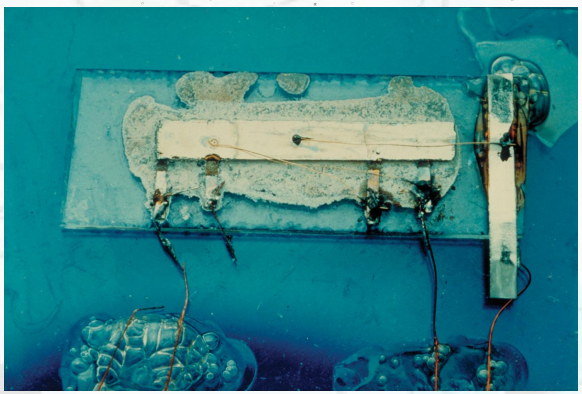

June 23, 1964 J. S. KILBY 3,138,743
MINIATURIZED ELECTRONIC CIRCUITS
Filed Feb. 6, 1959 4 Sheets-Sheet 2

Fig. 6a

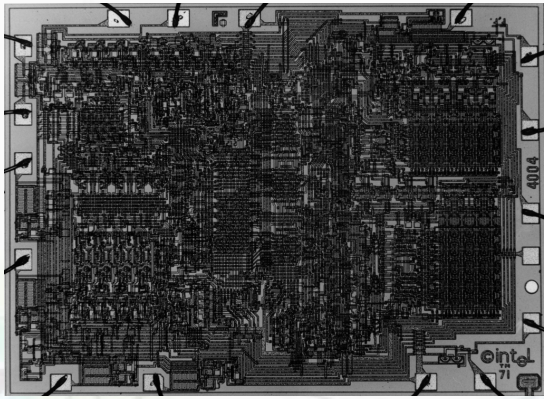
Fig. 6b

INVENTOR
Jack S. Kilby

BY Stevens, Davis, Miller & Mosher ATTORNEYS



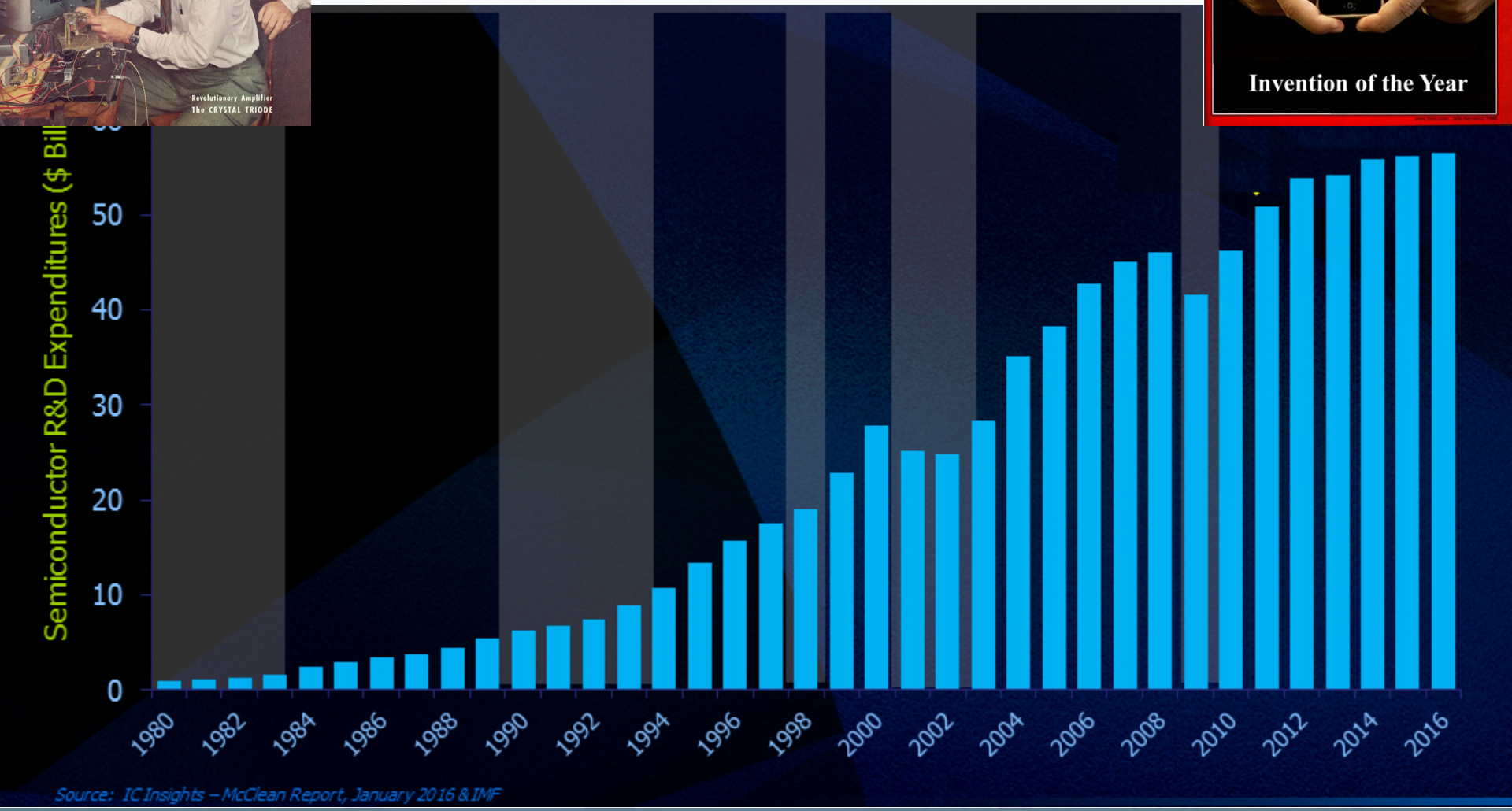
Microprocessor (4004)
Intel 1971



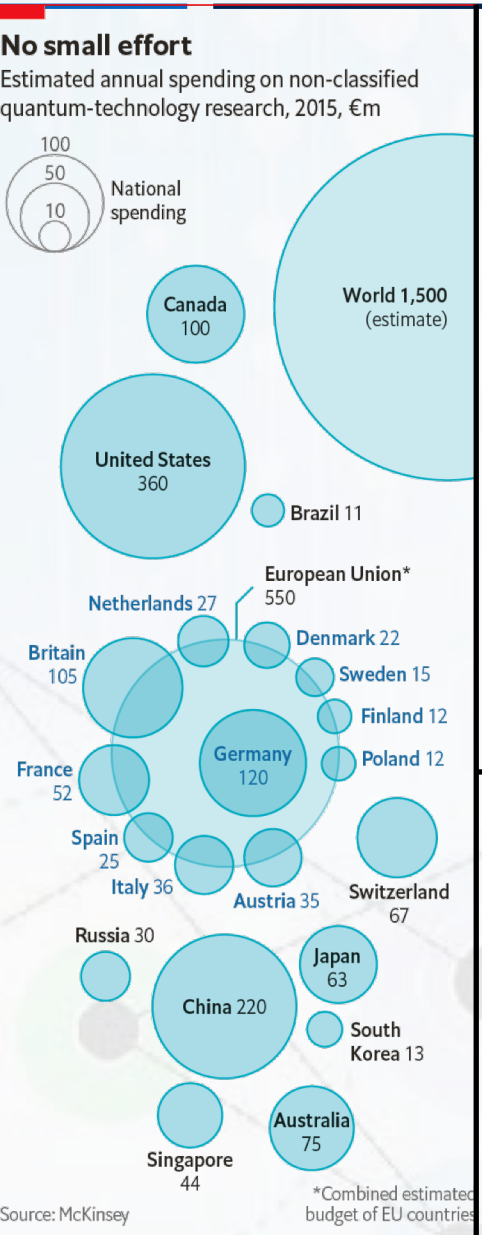

SEPTEMBER · 1948
electronics
A McGRAW-HILL PUBLICATION
Revolutionary Amplifier
The CRYSTAL TRIODE

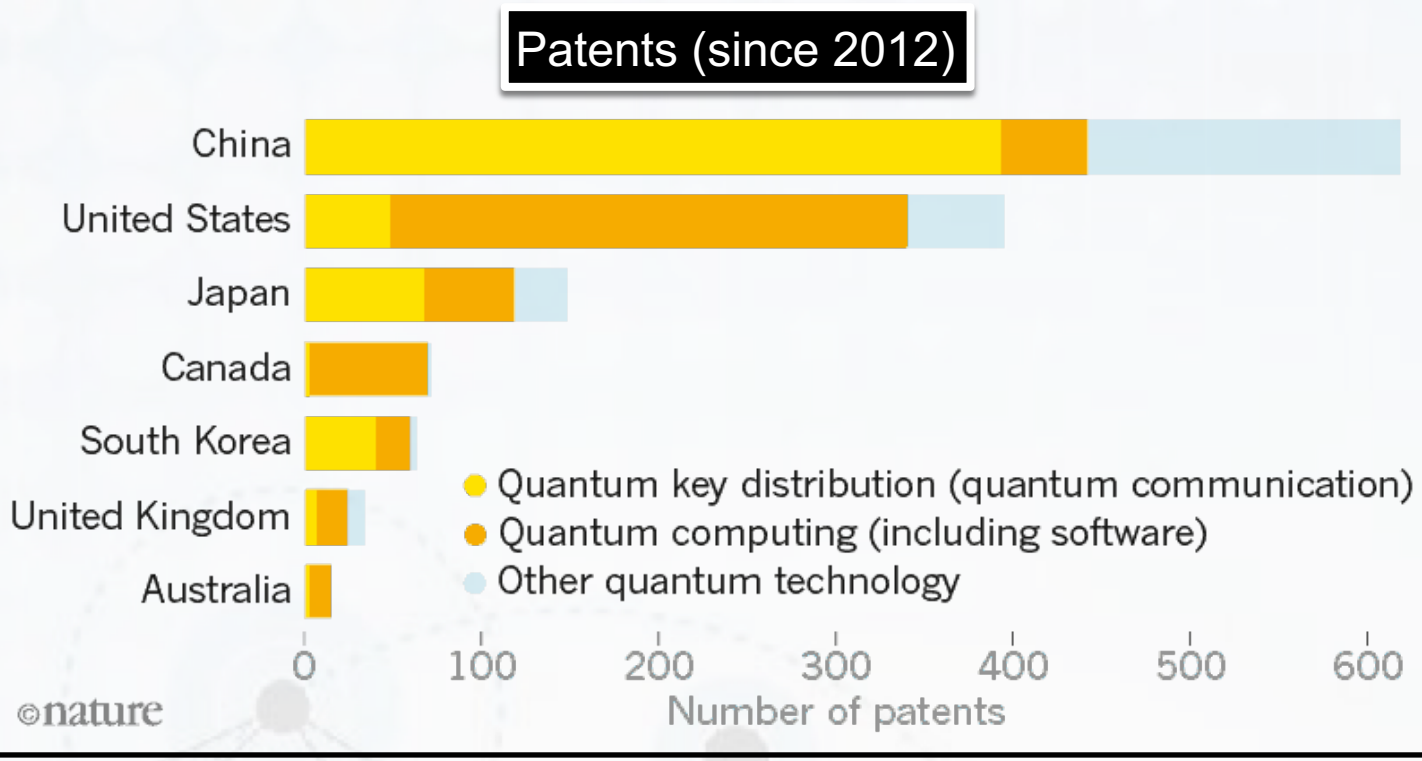
$1 TRN in R&D


TIME
Is Microsoft dead?
Invention of the Year


Semiconductor R&D Expenditures ($ Bil
0
10
20
30
40
50
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Source: IC Insights – McClean Report, January 2016 & IMF

WE ARE NOT ALONE





Sample Investments:

US National Quantum Initiative $1.25B

Russia $790M

China $400M

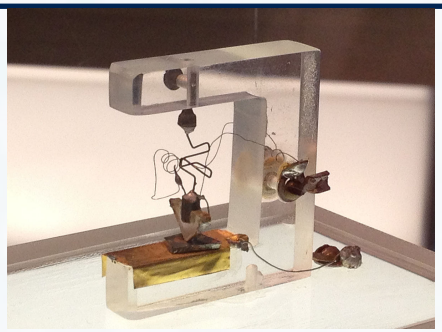
EU Quantum Flagship Program $1.1B

Germany $725M

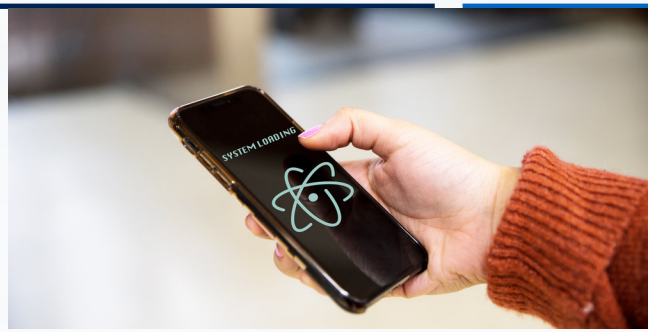
…

OUR ROLE

Early days:
We are here



Don't expect your quPhone too soon



Fundamental research to advance Quantum Information Science

- Address grand challenges needed to drive science and technology
- Apply cross-lab expertise in qubits, materials, computing, applications, …
- Collaborate with academia and industry:

'THE QUANTUM INFORMATION EDGE' STRATEGIC ALLIANCE LAUNCHED IN THE U.S.

PUBLISHED ON DECEMBER 23, 2019 BY THE QUBIT REPORT

BERKELEY LAB

Sandia National Laboratories

Berkeley UNIVERSITY OF CALIFORNIA

UNIVERSITY OF MARYLAND 18 56

Duke UNIVERSITY

MIT Lincoln Laboratory

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

VE RI TAS HARVARD

THE UNIVERSITY OF NEW MEXICO 1889

University of Colorado Boulder

Massachusetts Institute of Technology

+ industry partners and growing …