PHYS 150: Physics

INSTRUCTOR

Michel van Veenendaal

Office: La Tourette-223, Phone: 815-753-0667 or 630-252-4533

E-mail: veenendaal@niu.edu

Office Hours: Tuesdays and Thursdays from 2-3pm

Web page: www.niu.edu/~veenendaal/150.htm

La Tourette Hall

Goal of the course:

- Teach physics
- Try to make you think a little like a physicist
    - Look at the world in terms of (mathematical) models
    - Critical (scientific) thinking

I am from the Netherlands

Oldest tricolor flag

16.8 million inhabitants

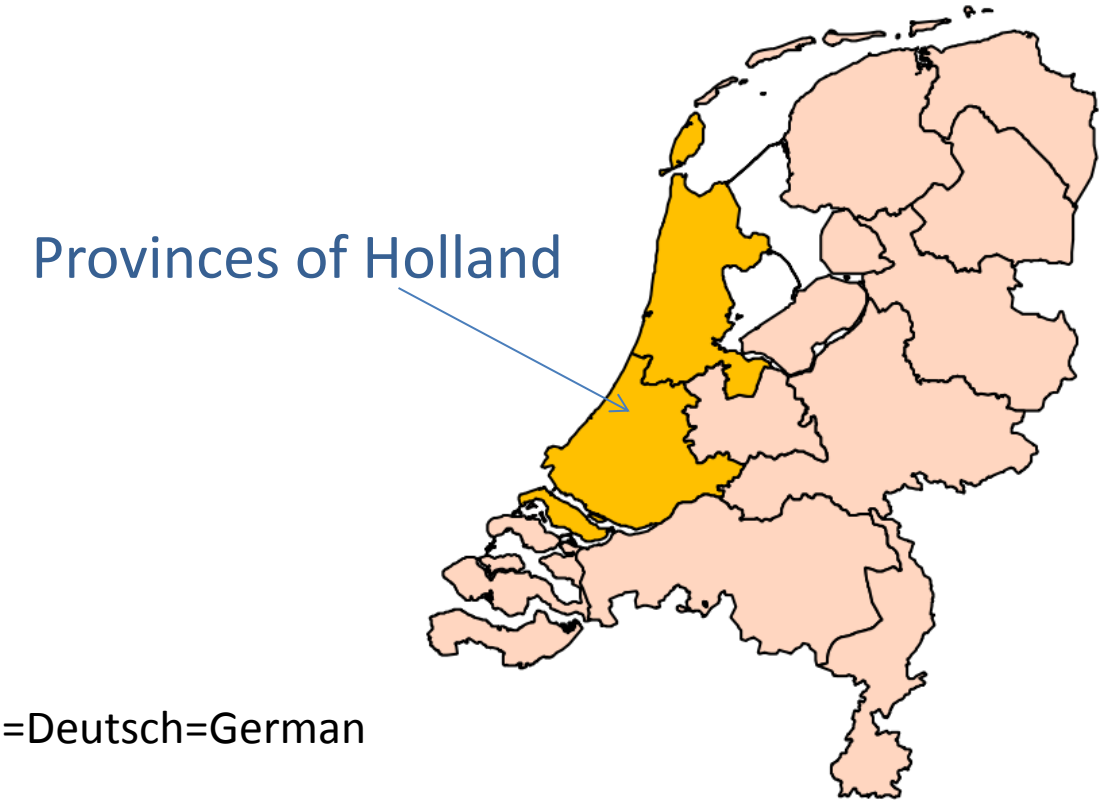
Cf.
France: 65 million
Great-Britain: 62 million
Germany: 82 million

Illinois: 12.9 million
Florida: 19.3 million


De Kalb
Chicago
Naperville
Amsterdam
Rotterdam
The Hague
Utrecht
Eindhoven
Antwerpen
Bruxelles
Brussel
Gent
Groningen
Leeuwarden
Zwolle
Arnhem
Nijmegen
Tilburg
Breda
Dordrecht
Leiden
Haarlem
Almere
Amersfoort
Apeldoorn
Deventer
Enschede
Hoogeveen
Emmen
Assen
Meppel
Kampen
Lelystad
Alkmaar
Hoorn
Den Helder
Wieringen
Sneek
Heerenveen
Wolvega
Emmeloord
Dronten
Almelo
Nordhorn
Bocholt
Kleve
Venlo
Roosendaal
Oosterhout
's-Hertogenbosch
Oss
Zutphen
Barneveld
Ede
Zoetermeer
Delft
Gouda
Schiedam
Spijkenisse
Hellevoetsluis
Middelburg
Vlissingen
Goes
Bergen op Zoom
Essen
Hoogstraten
Turnhout
Brecht
Brasschaat
Knokke-Heist
Blankenberge
Oostende
Brugge
Middelkerke
Jabbeke
Koksijde
Zedelgem
Maldegem
Sint-Niklaas
Wilrijk
Lier
Herentals
Mechelen
Heist-op-den-Berg
Lokeren
Diksmuide
Dunkirk
Gravelines
Roeselare
Ieper
Kortrijk
Waregem
Aalst
Vilvoorde
Evere
Leuven
Hasselt
Maastricht
Heerlen
Aachen
Genk
Meeswijk
Mol
Geel
Deurne
Weert
Mönchengladbach
Neuss
Krefeld
Dusseldorf
Wuppertal
Solingen
Leverkusen
Ehrenfeld
Lindenthal
Cologne
Porz
Bonn
Hennef
Erftstadt
Düren
Wickrath
Duisburg
Essen
Oberhausen
Bochum
Gelsenkirchen-Nord
Dorsten
Marl
Recklingha
Velbert
Hagen
Witten
Bad Bentheim
Rheine
Ochtrup
Gronau
Steinfurt
Heek
Ahaus
Dülmen
Bocholt
Hazebrouck
Tourcoing
Wavre
Saint-Omer
20 mi
20 km

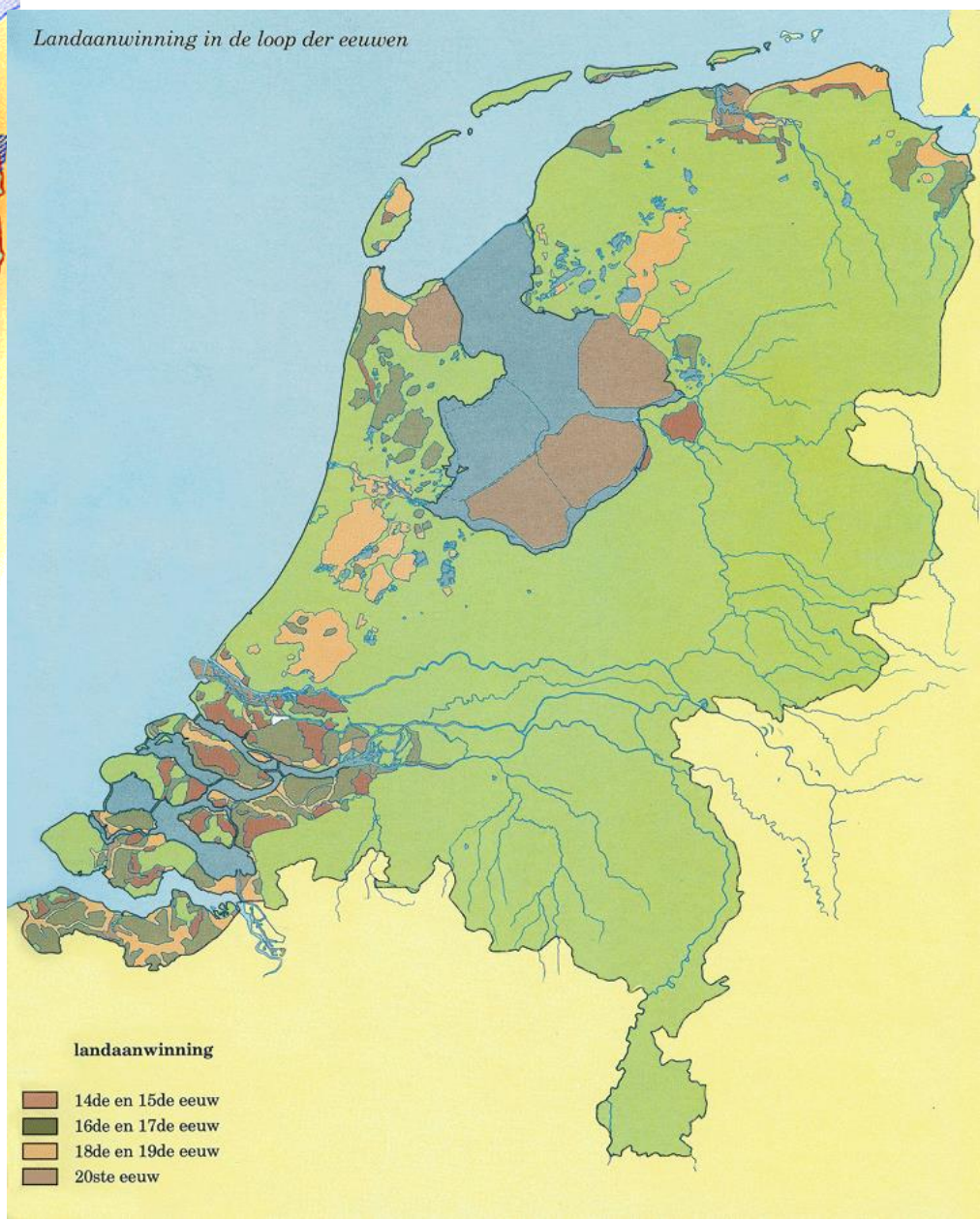
First:

	English	Nederlands
Country	The Netherlands (not Holland)	Nederland
People	Dutch	Nederlanders



We had nothing to do with those: Dutch=Deutsch=German

40% below sea level



Some were a bit more challenging

Haarlemmermeerpolder
1849-1852
185 km^2

Steam power!

Amsterdam Airport
Also known as Schiphol, which probably stands for Ship's hell

Holland is famous for its painters

The country where biking is a mode of transportation


WHERE's WALDO?

Why Orange?

Royal Family: House of Oranje-Nassau

Principality of Orange

The Pilgrim Fathers came to America in 1620 and founded the city of Plymouth

Which turned into…..

In 1614 (6 years earlier), the Dutch established New Amsterdam

The city of Amsterdam in New Netherlands

Which turned into:

Before moving to America, they lived in the Netherlands for about 14 years

They found religious freedom in the Netherlands, but they felt that the Dutch "morals were much too libertine"

"Although they prospered in Holland they were concerned because their children were influenced by the Dutch culture. "

So much for freedom….

Staten Island named after the Dutch Staten Generaal

The Bronx named after Johan Bronck

Harlem=Haarlem

Brooklyn=Breukelen

Flushing=Vlissingen

You know that wall that the Dutch built to keep the native Americans away?

De Waalstraat became

Wall Street

The end of all this misery

England kept Manhattan

Dutch got the island of Run

Because, hey, we can't live without

nutmeg….

Maybe you think of Dutch physicists

Lorentz 1903 | Zeeman 1903 | van der Waals 1910 | Kamerlingh-Onnes 1913 | Zernike 1953 | van der Meer 1984 | 't Hooft 1999 | Veltman 1999 | Geim 2010

9 Nobel prizes

USA 85 Nobel prizes in physics
Rescale population

UK	23/63.2 x 16.75=6.1
Germany	25/81.8 x 16.75=5.1
USA	85/315.1 x 16.75=4.5
France	13/65.4 x 16.75 =3.3
Italy	6/60.8 x 16.75=1.7
Canada	3/35.0 x 16.75=1.4
China	2/1353 x 16.75=0.02
Belgium	0

1986-1990

Delft University of Technology

1842 founded by King William II
To train civil servants for the
Dutch East Indies

Title: Ingenieur

1990-1994
Ph.D. University of Groningen

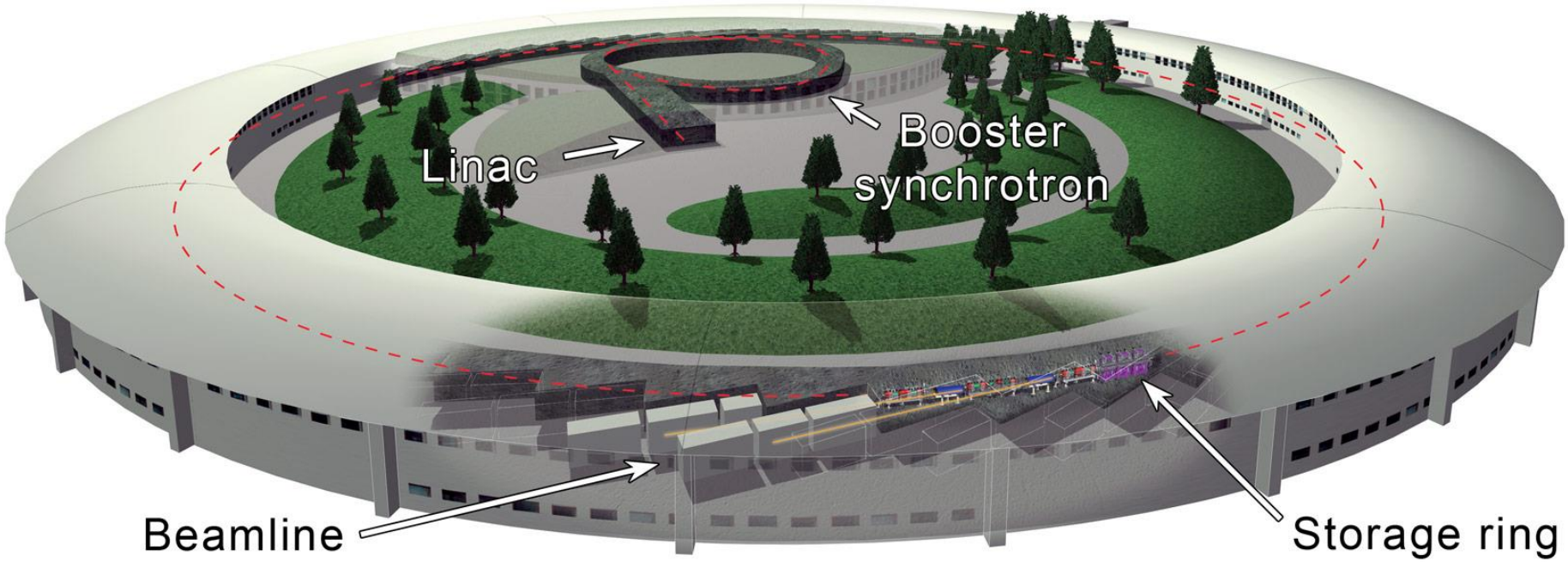
Title: Dr.

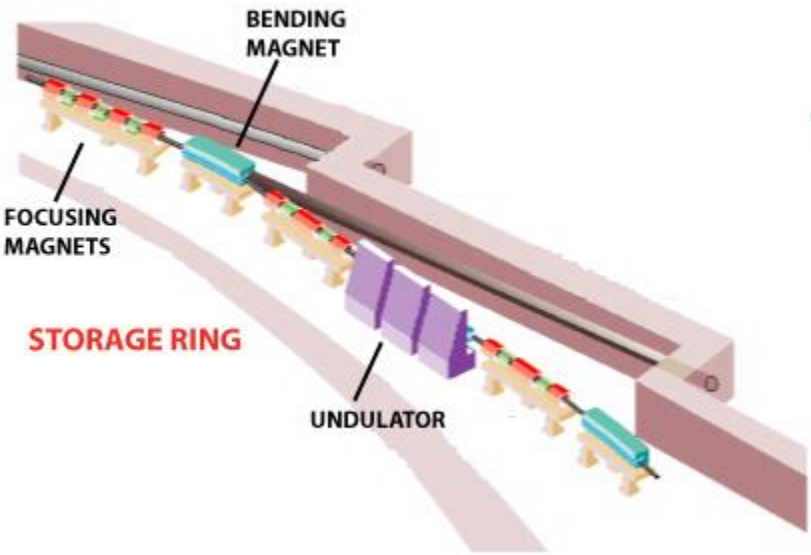
Now Dr. Ir.

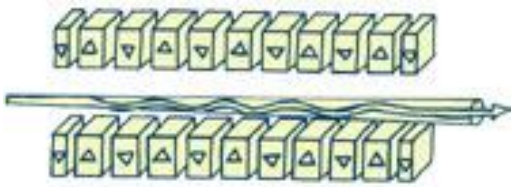
Founded 1614
(compared Harvard 1636)

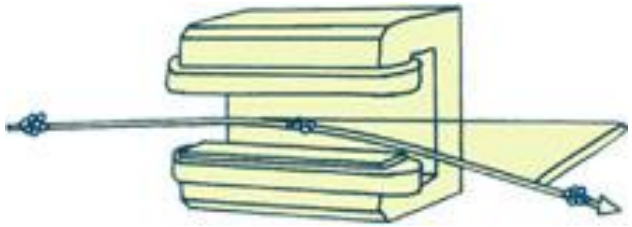
1994-1997 European Synchrotron Radiation Facility

What is a synchrotron? A giant source of X-rays

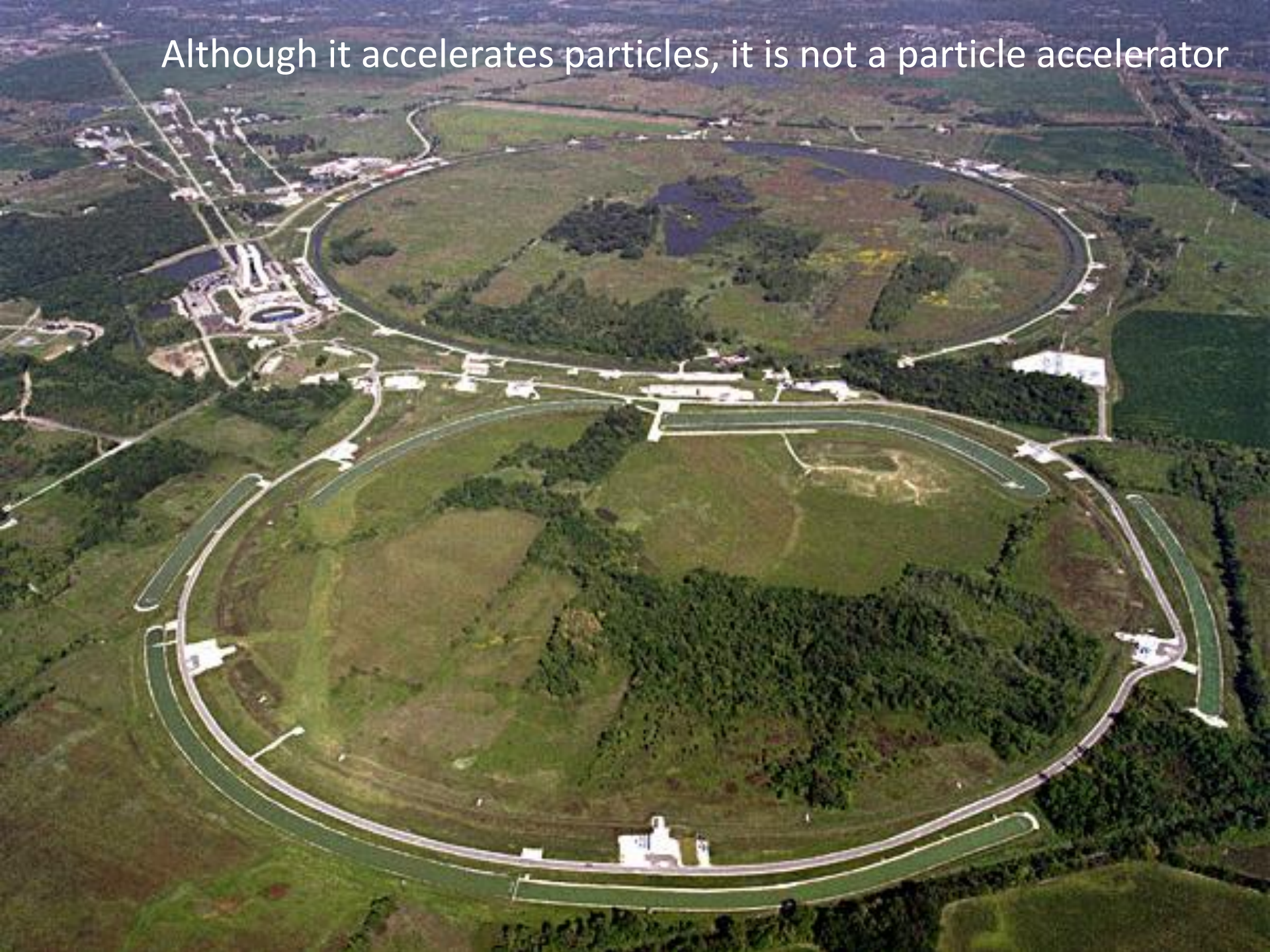




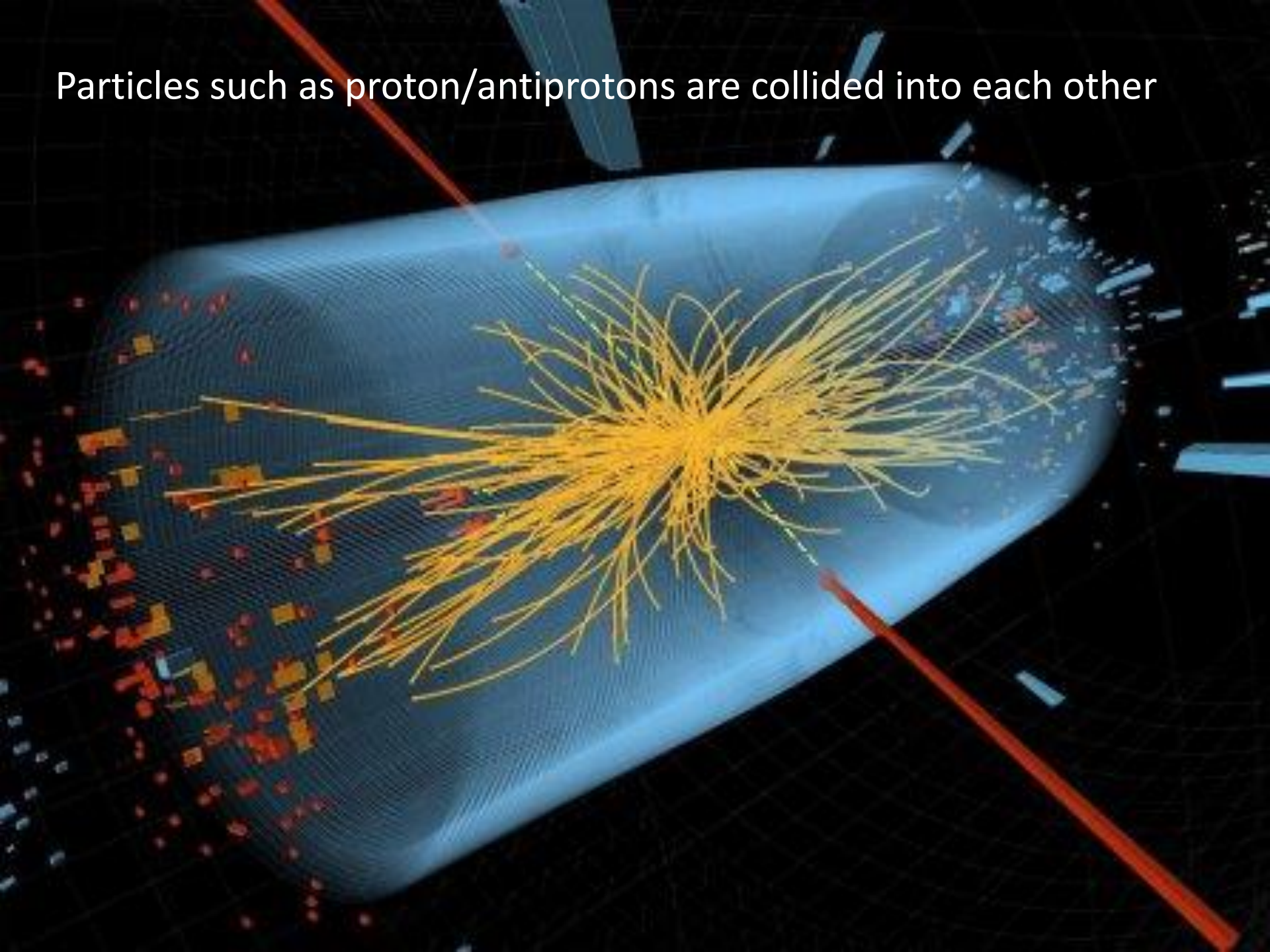




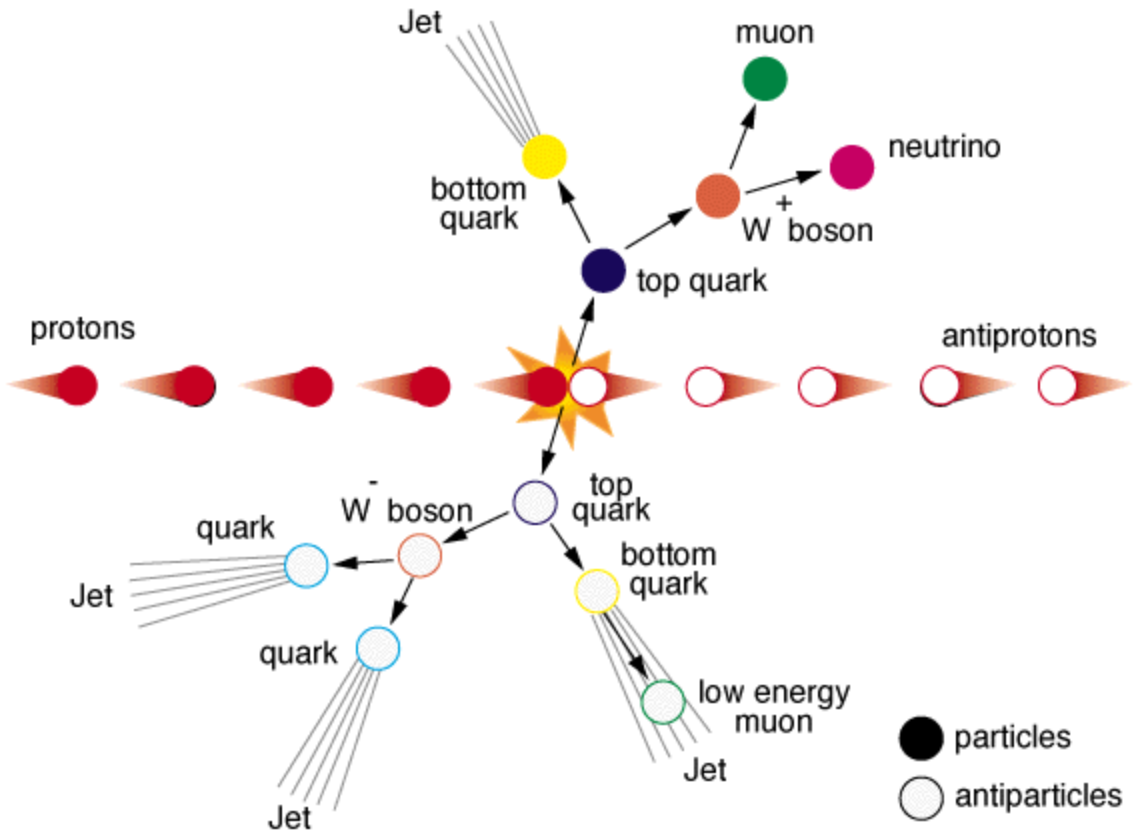
Although it accelerates particles, it is not a particle accelerator



Particles such as proton/antiprotons are collided into each other

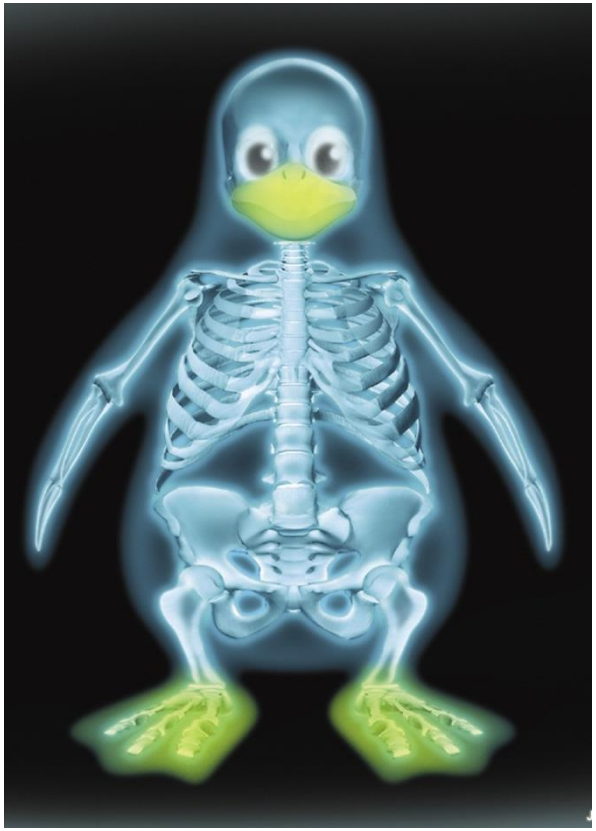


In the collision, exotic particles, such as quark, can be produced. One is looking at the decay products of these particles.

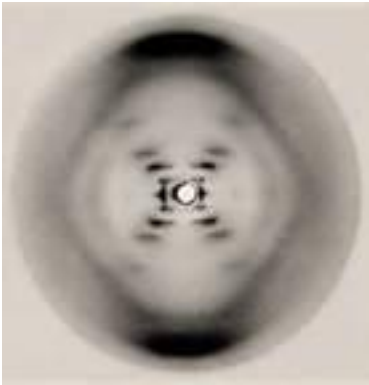


A Top Antitop Quark Event from the D-Zero Detector at Fermilab

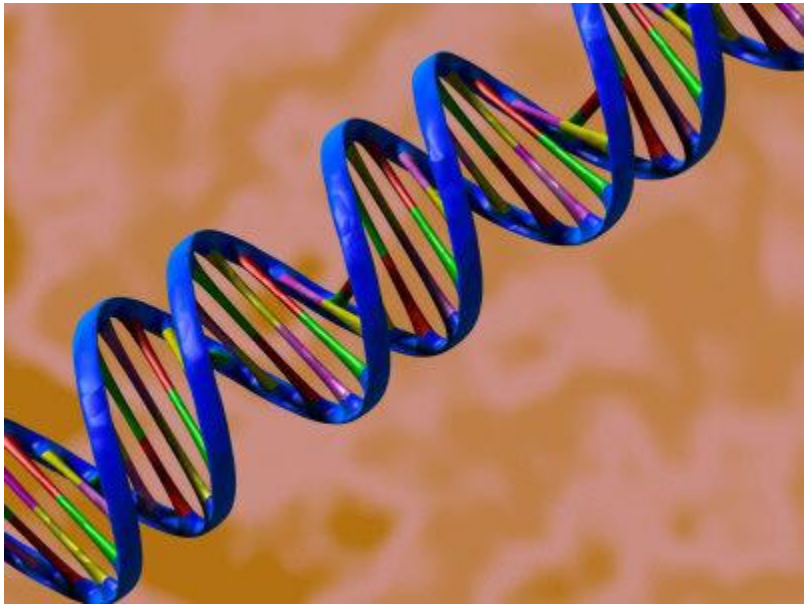
What can you do with X-rays, besides the usual?



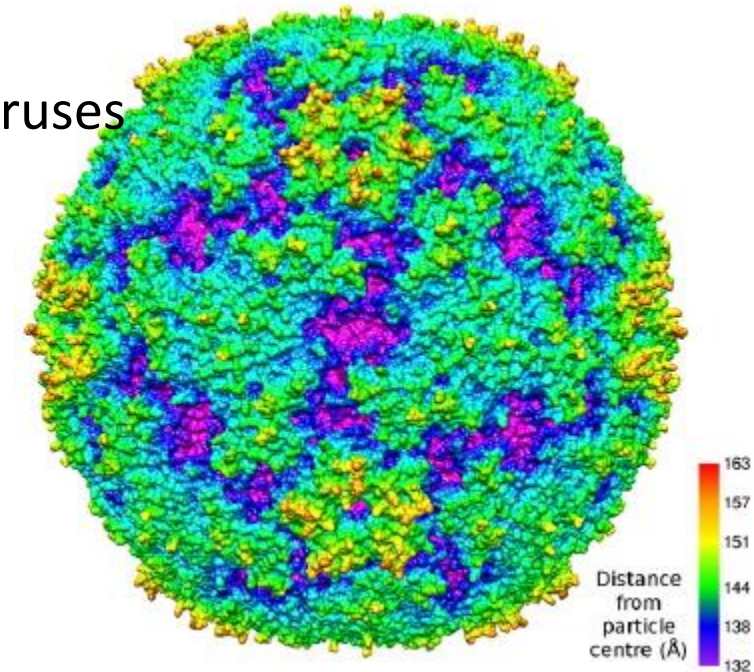
Determine the structure of crystals and molecules

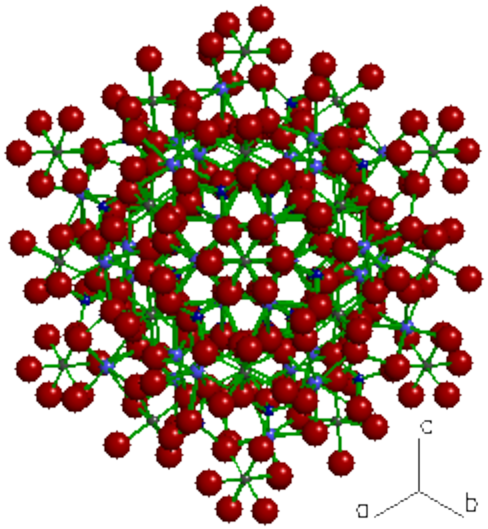


DNA

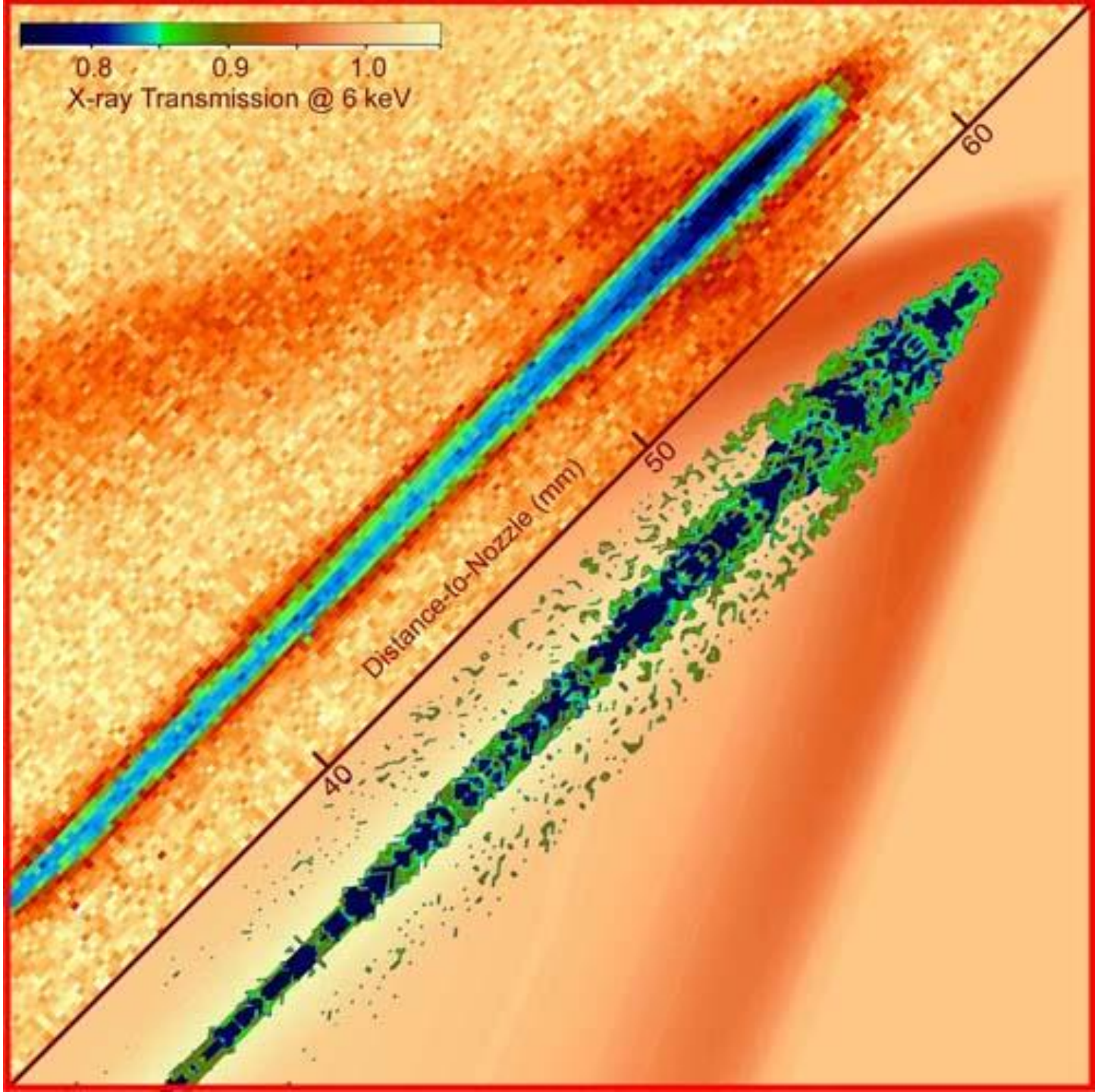


Or viruses

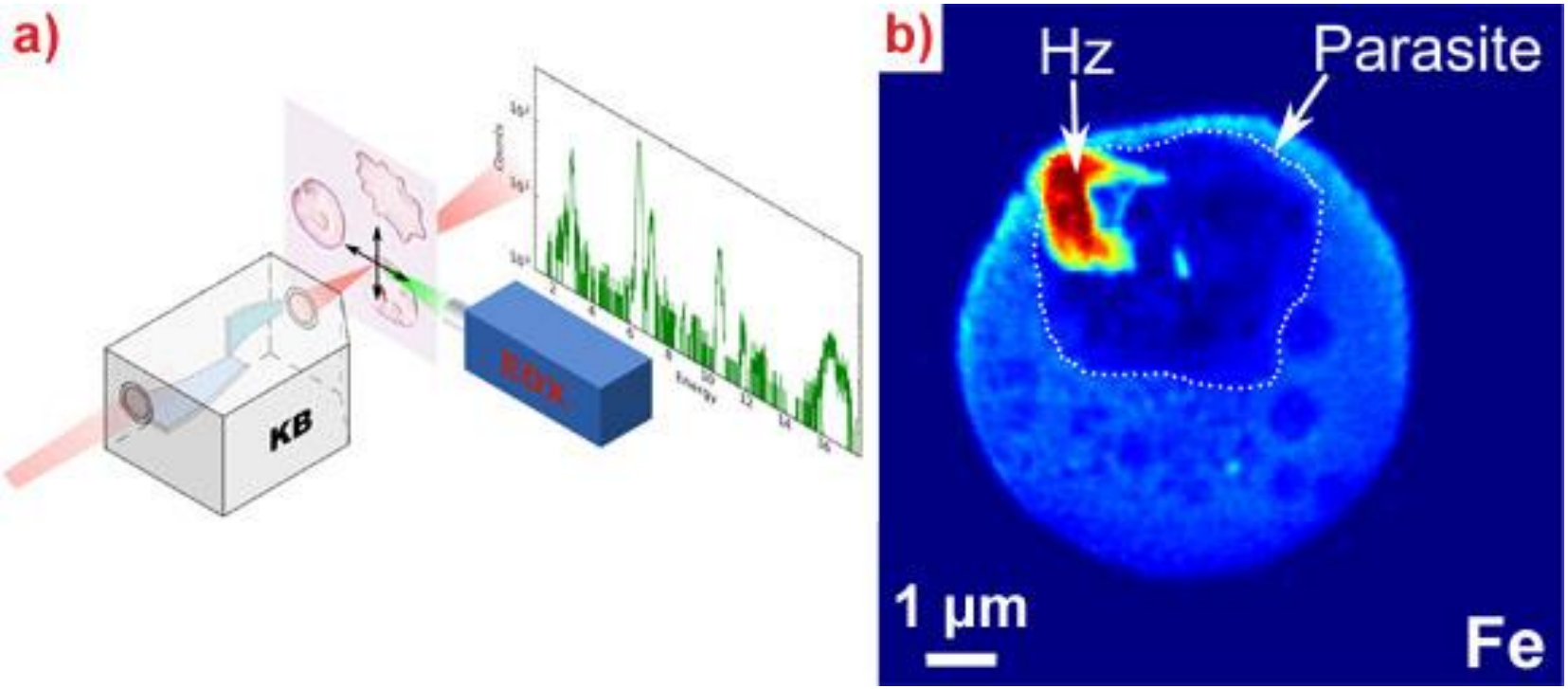




We can look inside fuel sprays

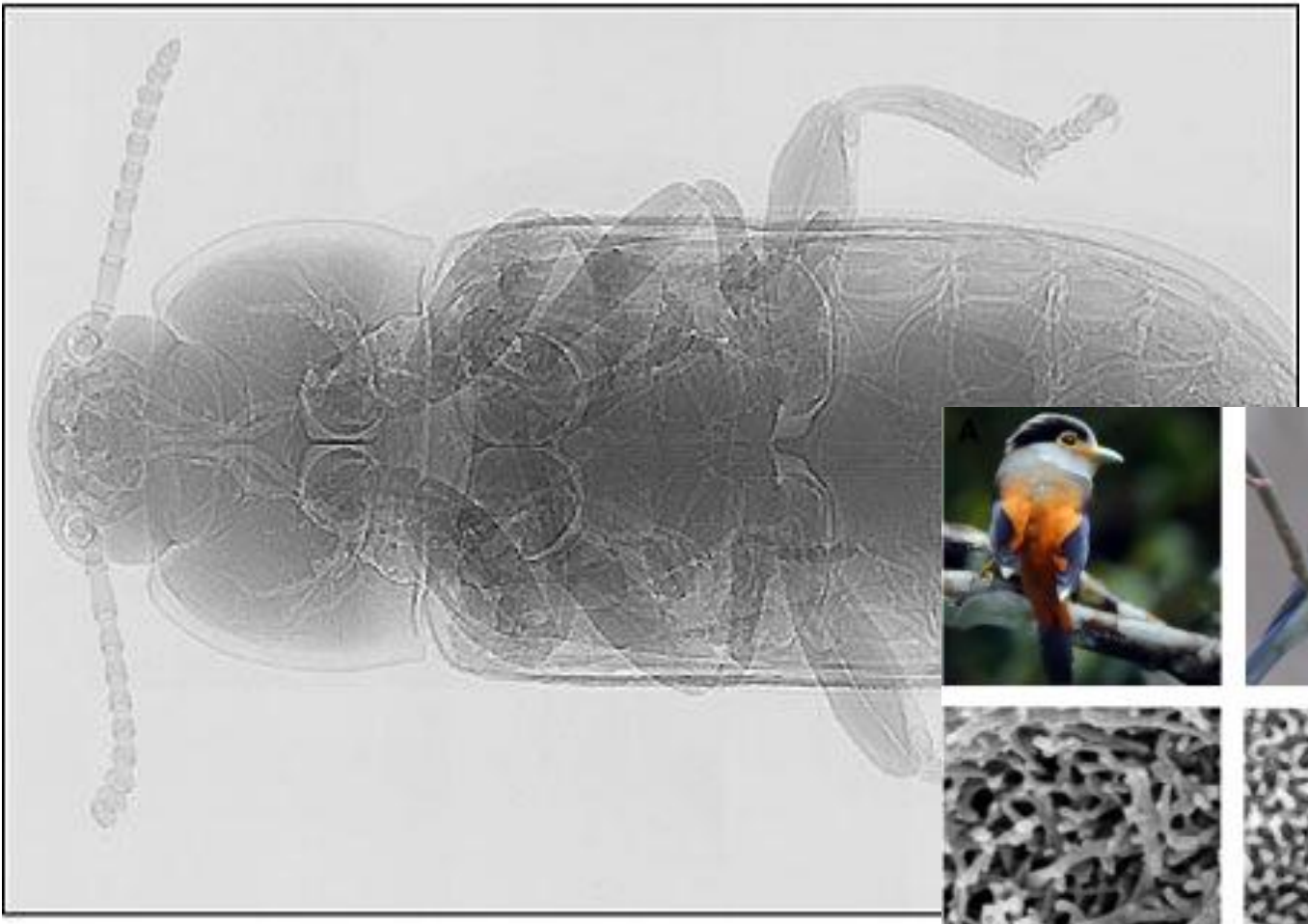


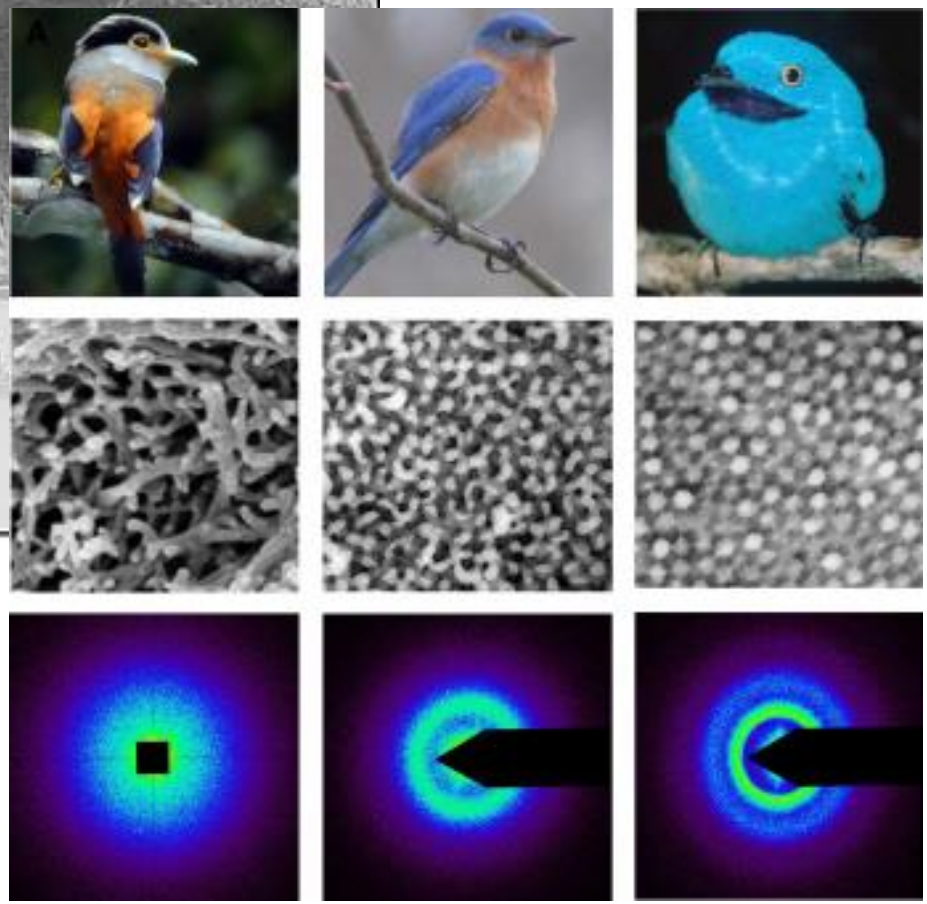
X-ray microscopy



X-ray fluorescence microscopy reveals the location of iron in a red blood cell infected with a malaria parasite.

It can show that insects can breathe!





It provides insight into the different blues of birds

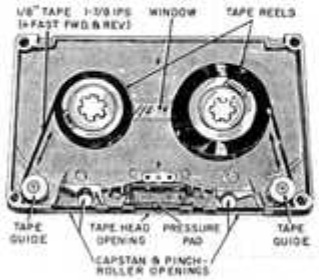
1997-98 postdoctoral position at NIU

Northern Illinois University

1998-2002 Philips Research
Senior Research Scientist

Magnetic Recording History Pictures 4

Philips Compact Cassette

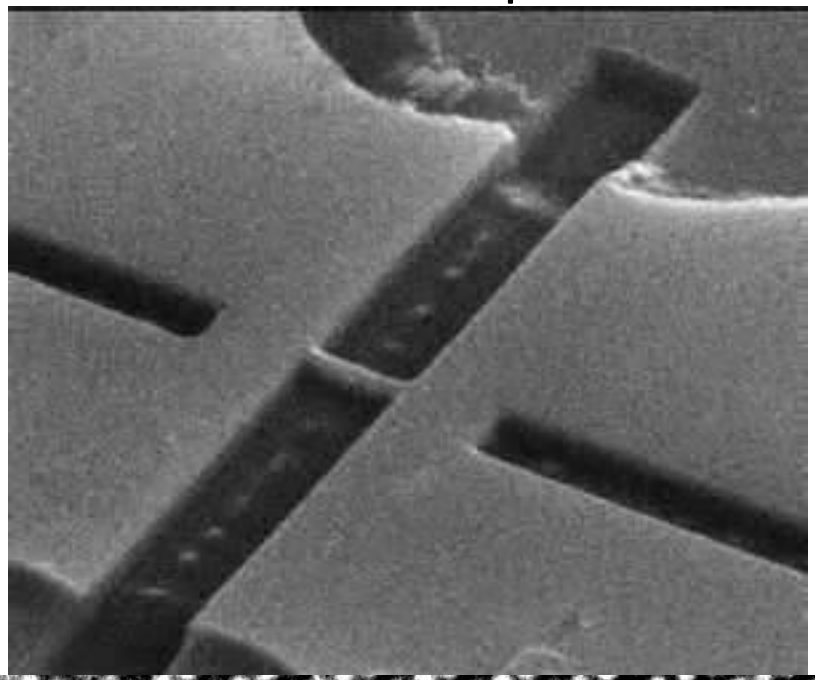


Philips of 1965, from *Electronic World*, Nov. 1966

Philips of 1965, from *Electronic World*, Nov. 1966

Co-invented the CD player

Electronic Microscopes



Northern Illinois University

2002 Associate Professor
Title now: Prof. Dr. Ir.

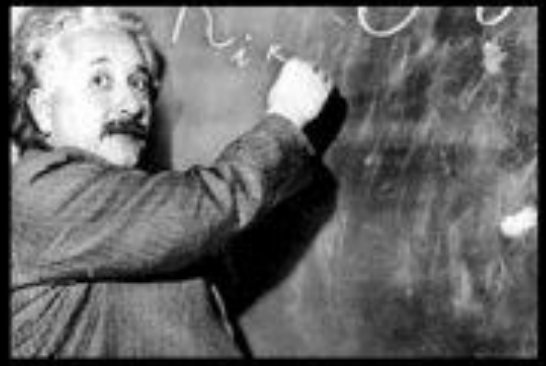
2008 Professor
2009 Presidential Research Professor
2013 Distinguished Research Professor
(Essentially a retired PRP)

No not you, the NIU president

2005 joint position with Argonne National Laboratory

SCIENCE TEACHER

What my friends think I do



What my mom thinks I do

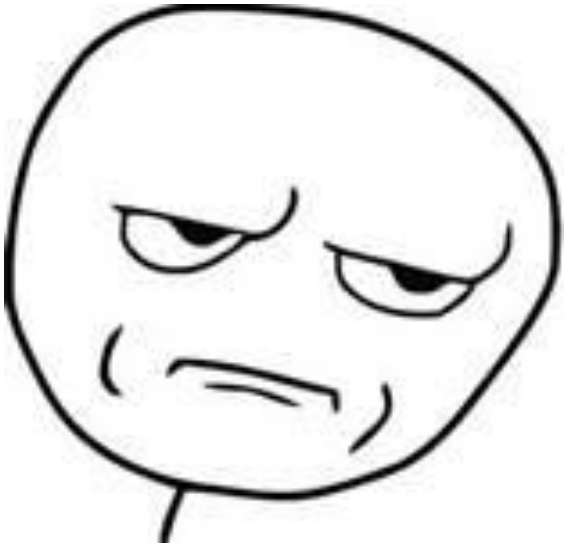
What society thinks I do

What my students think I do

What I think I do

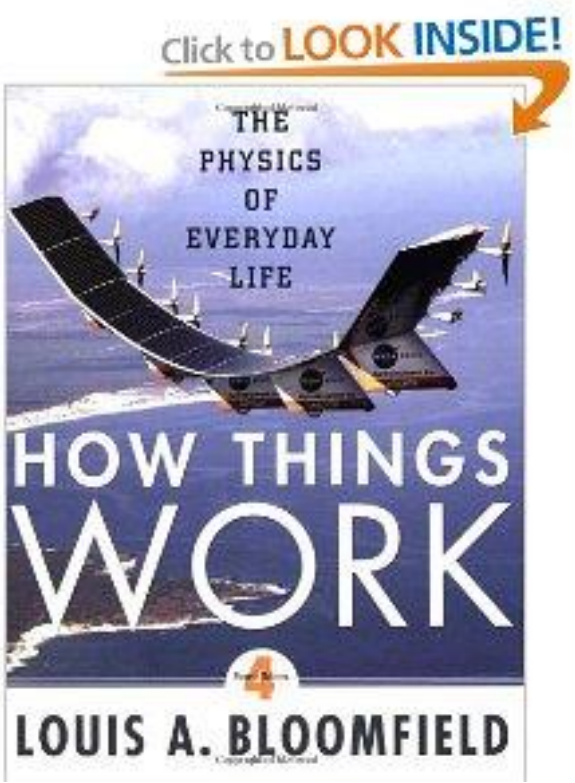
What I do

All right back to Physics 150…



This is what my wife says she feels about physics

BOOK: MWF Class:



Lyle Marschand

Skating, falling balls, and bumper cars are included
to explain the Laws of Motion.
Air conditioners and automobiles are used
to explore thermodynamics

Sounds like fun

In the end, it just reads like any other physics books

Skates almost completely eliminate friction, at least in one direction, so that you can glide effortlessly across the ice or roller rink and experience your own inertia. For simplicity, imagine that your skates are perfect and experience no friction at all as you glide. Also, for this and the next couple of sections, let's forget not only about friction but also about air resistance. Since the air is calm and you're not moving too fast, air resistance isn't all that important to skating anyway.

Now that you're ready to skate, we'll begin to examine five important physical quantities relating to motion and look at their relationships to one another. These quantities are position, velocity, mass, acceleration, and force.

Let's start by describing where you are. At any particular moment, you're located at a **position**—that is, at a specific point in space. Whenever we report your position, it's always as a **distance** and **direction** from some reference point: how many meters north of the refreshment stand or how many kilometers west of Cleveland.

Position is an example of a vector quantity. A **vector quantity** consists of both a magnitude and a direction; the **magnitude** tells you how much of the quantity there is, while the direction tells you which way the quantity is pointing. Vector quantities are common in nature. When you encounter one, pay attention to the direction part; if you're looking for buried treasure 30 paces from the old tree but forget that it's due east of that tree, you'll have a lot of digging ahead of you.

You're on your feet and beginning to skate. If you're moving, then your position is changing. In other words, you have a velocity. **Velocity** measures how quickly your position changes; it's our second vector quantity and consists of the speed at which you're moving and the direction in which you're heading. Your **speed** is the distance you travel in a certain amount of time,

$$\text{speed} = \frac{\text{distance}}{\text{time}},$$

With just as many words as an average Harry Potter

But without:

Ok, let's try to read it:

Now that you're ready to skate, we'll begin to examine five important physical quantities relating to motion and look at their relationships to one another. These quantities are position, velocity, mass, acceleration, and force.

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This course:

No book. Lecture notes to be at www.niu.edu/~veenendaal/150.htm

Pros

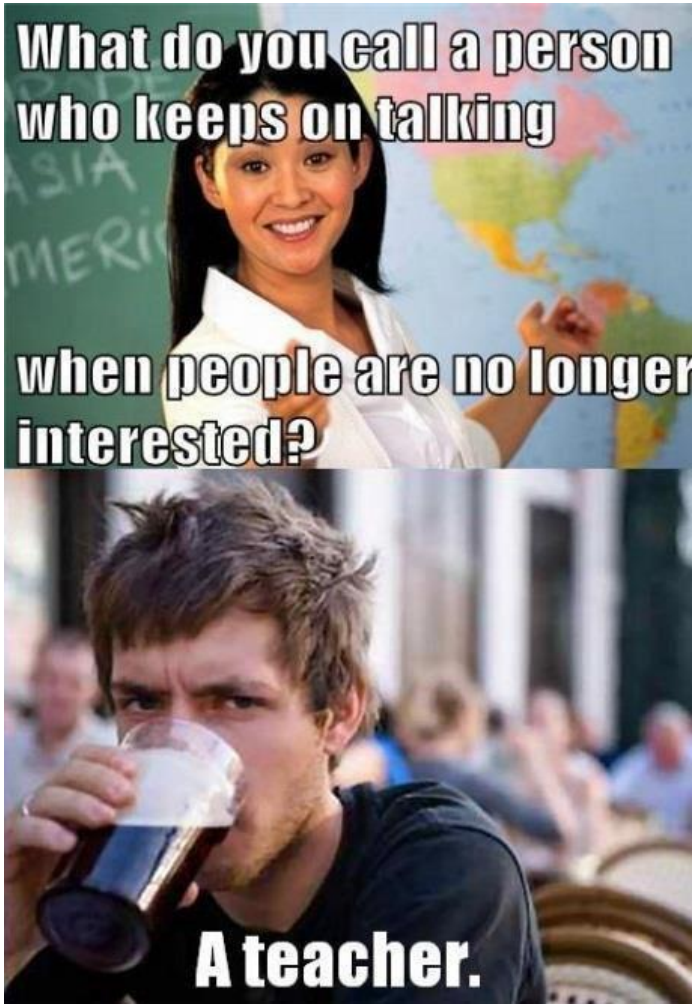
- They're free (yeah!)
- They have some nice equations!

Cons

- They're written by me
- They have some nice equations!

Please let me know if you find error/mistakes

Exercise and homework files will be posted along the way



All course information is on blackboard

Let me know if you have problems finding something!

CLASS MEETINGS: Lecture Section 1: T/Th 3.30-4.45 pm, Tourette 200

Instructor: Michel van Veenendaal, Tourette 223; 815-753-0667
Office Hours: **Tuesday/Thursday 1.30-3.30PM,** or by appointment.
Email: veenendaal@niu.edu
Web page: See blackboard

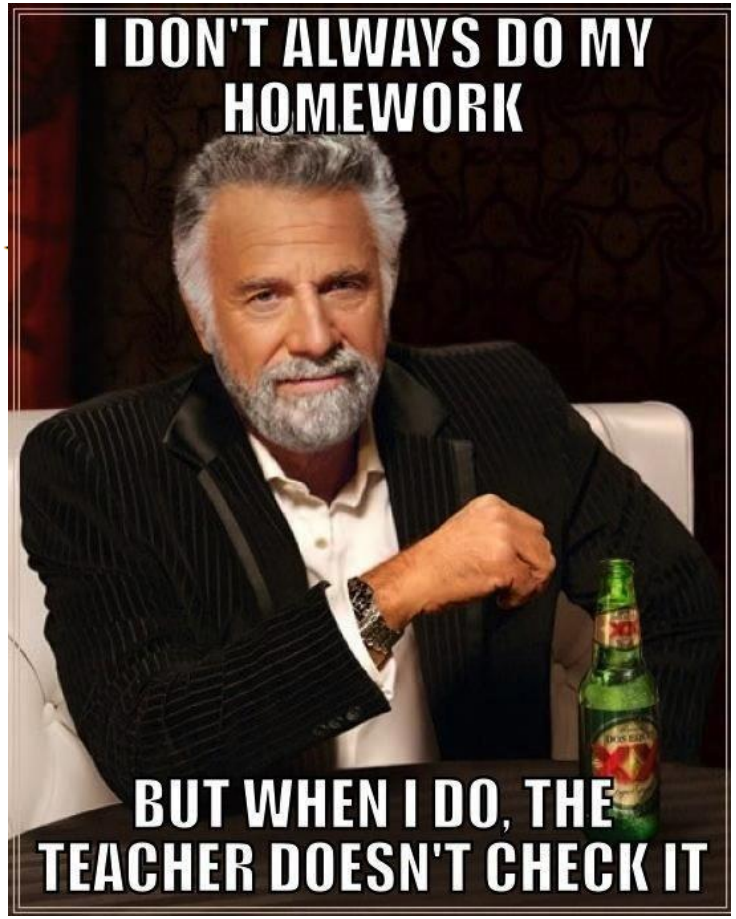
Note: Honors students will be required to do a special project – see me to discuss.

SCHEDULE OF TESTS:

TEST 1	**Tuesday 9/24**
TEST 2	**Thursday 10/17**
TEST 3	**Tuesday 11/19**

FINAL **Tuesday, 12/10, 4-5.50pm** (be aware of potential exam conflicts)

Homework is not graded.



MINIMUM REQUIREMENTS TO PASS THE COURSE:

1. Take 2 of the exams and the Final exam
2. Pass the Lab (150A students only).

WARNING:
The final grades are curved.

Marschand's class: Grading system that you are probably used to

Scale:	100 - 88	A
	87- 75	B
	74 - 62	C
	61 - 50	D

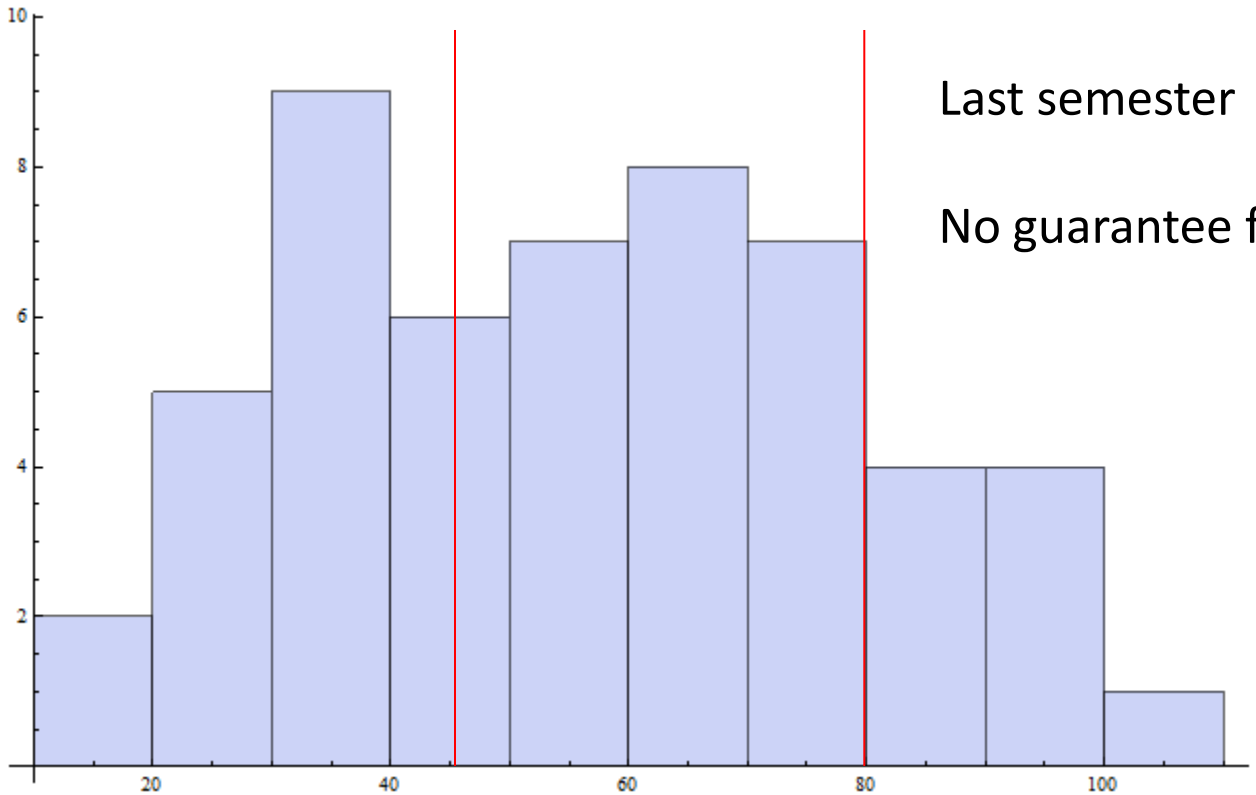
A – 16%
B – 31%
C – 31%
D – 10%
F – 13%

More senior undergraduate/graduate-type grading

The final grades are curved. Therefore, the final grade depends on the distribution of the grades. Typical relationships between the weighted tests/final and the grades are

A	> 80±5
B	65±5 - 80±5
C	45±5 - 65±5
D	TBD

Note that these ranges are indicative and that the instructor remains the right to change the values depending on the performance of the students and the difficulties of the exams.



Last semester

No guarantee for this semester!

Marschand

- Exams are “easier”
- Grading is very strict
- Percentage A, B, C, etc.

A – 16%
B – 31%
C – 31%
D – 10%
F – 13%

- Make you feel more comfortable, since you can answer more questions correctly

MvV

- Exams are more difficult
- Grading is easier
- About the same (last semester I actually gave more A’s and B’s)

(I’m rather stuck to these historical statistics. We cannot favor one 150 class over another)

- Leaves you with a more uncomfortable feeling

What's the philosophy? Compare baseball

- I can throw "easy" balls at you and expect you to hit the ball 9 out of 10 times for an A
- You are well-trained for those balls

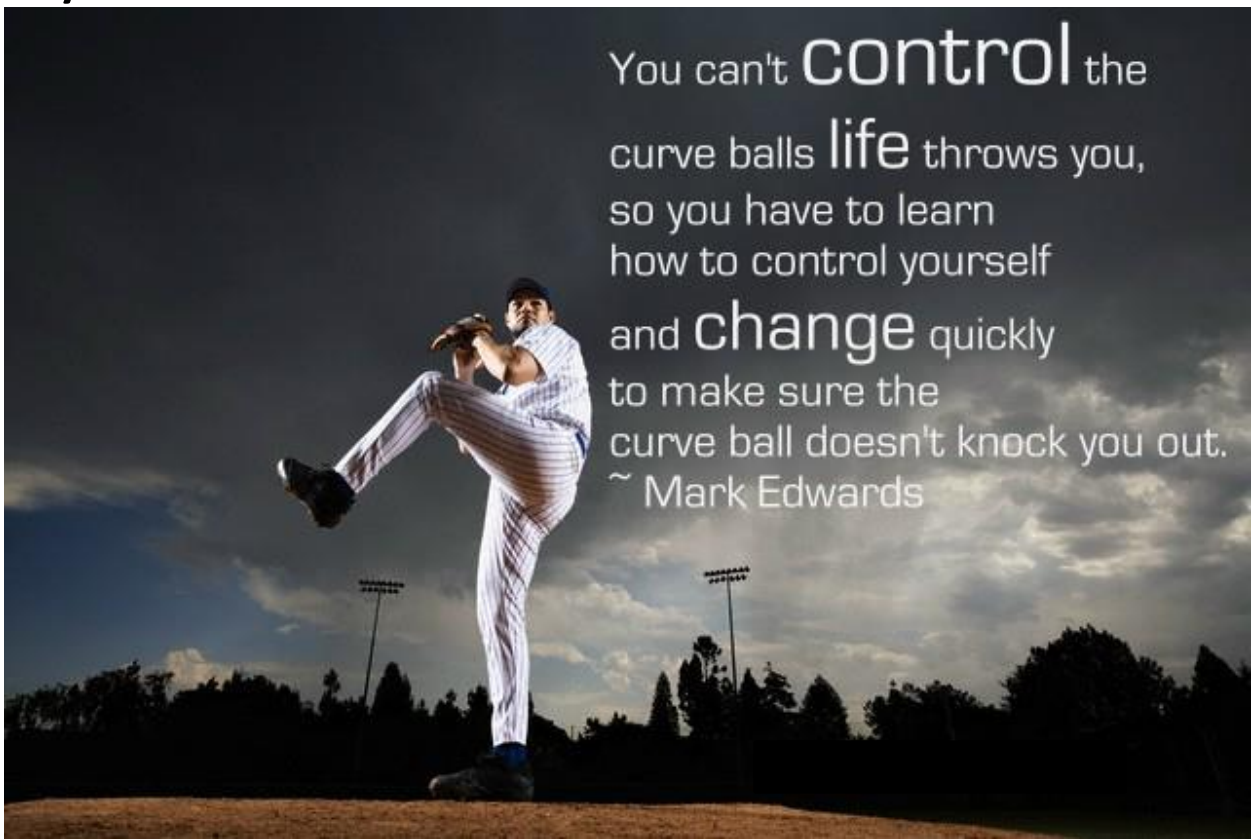
Scale:	100 - 88	A
	87- 75	B
	74 - 62	C
	61 - 50	D

- I can throw a couple of curveballs and fast balls as well and see how you perform on those.
- You are not always well-trained for all questions, but it shows me how you think on your feet.
- Since I don’t expect you to always do very well, the grading is more flexible.

Typical complaint: “The questions at the exam were different from those in class”

That’s exactly the point…

Life is not always “easy” balls



“If we had practiced harder on these questions, I would have had a better grade”

Not in this philosophy. The more practice you get on hard questions, the harder I have to make the exams.

Graduate physics students rarely score >90%. This does not mean they do not get A’s

Having people hit homeruns all the time is boring…

In essence:

Scoring that most of you are used to

A: Hits 90% of the “easy” balls
B: Hits 75% of the “easy” balls
C: Hits less

A: Hits the “easy” ones, and some/all of the curveballs and fastballs
B: Hits most of the “easy” balls, but has problems with the curveballs and fastballs
C: Has problems with the “easy” pitches

“If we had more testing opportunities, I would have had a better grade”

For ~80%, the final grade can be determined from a single test.

Since the final grades are curved, the points are less relevant. It’s the performance relative to the other students that determine the grade.

- You can get a 10 point bonus and still have exactly the same grades.

What is physics?

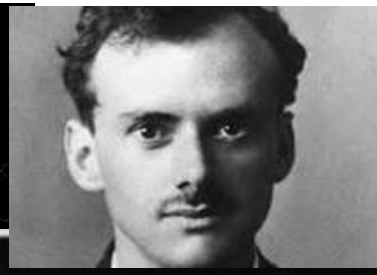
Wikipedia

Physics (from Ancient Greek: φύσις *physis* "nature") is a natural science that involves the study of matter[1] and its motion through space and time, along with related concepts such as energy and force. More broadly, it is the general analysis of nature, conducted in order to understand how the universe behaves.

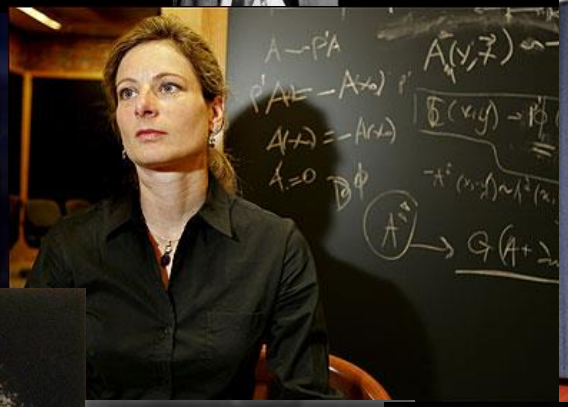
Chemistry, a branch of physical science, is the study of the composition, properties and behavior of matter. Chemistry is concerned with atoms and their interactions with other atoms, and particularly with the properties of chemical bonds. Chemistry is also concerned with the interactions between atoms (or groups of atoms) and various forms of energy (e.g. photochemical reactions, changes in phases of matter, separation of mixtures, properties of polymers, etc.).
Chemistry is sometimes called "the central science" because it connects physics with other natural sciences such as geology and biology.
Chemistry is a branch of physical science but distinct from physics.[5]

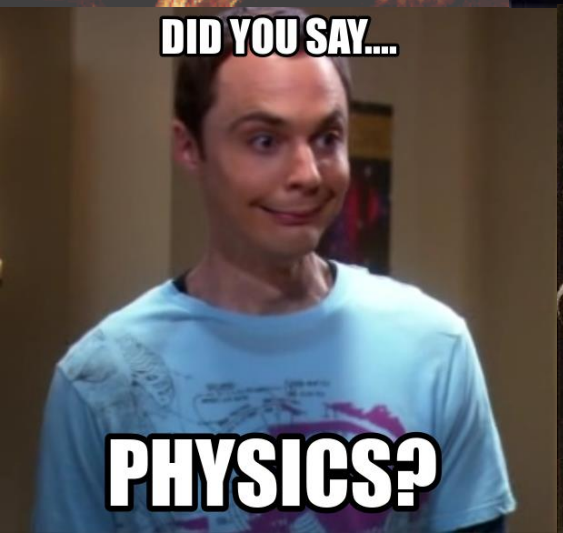
What is a physicist and how does a physicist look at the world?

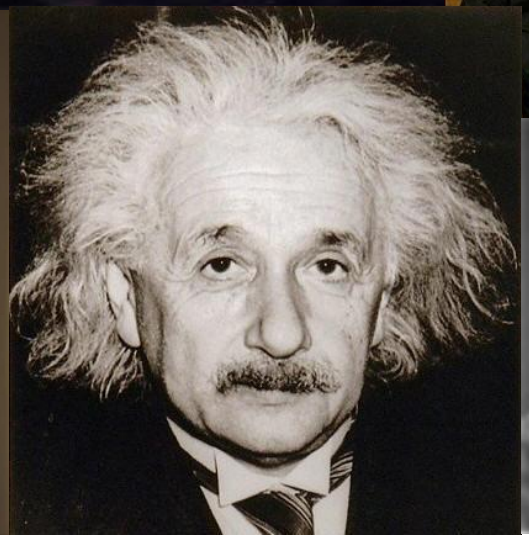




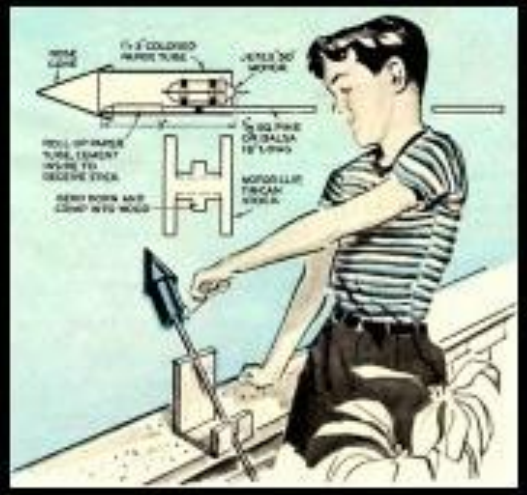




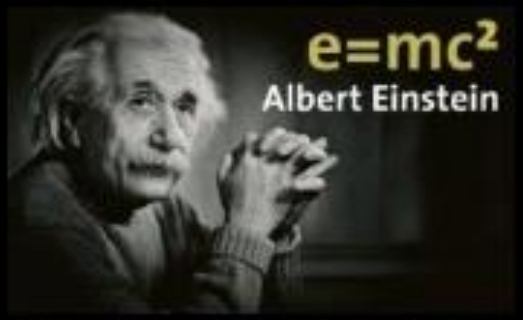


Physicists

What my friends think I do.



What my mom thinks I do.



What society thinks I do.

What my boss thinks I do.

What I think I do.

What I actually do.

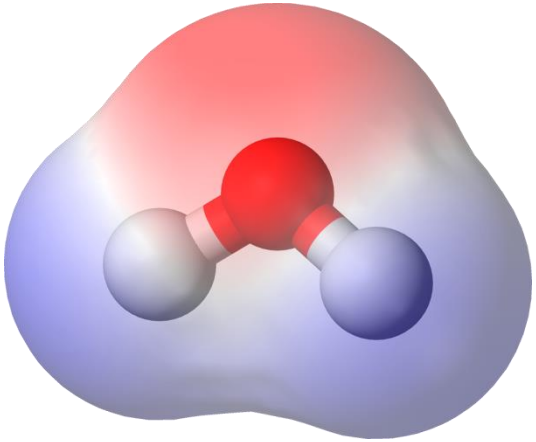
Let us look at some examples:

Most of you recognize this as a chemical reaction

$$2H_2 + O_2 \longrightarrow 2H_2O$$

However, why are molecules formed?

H_2O:



Linus Pauling
Quantum Chemist

This is due to chemical bonds

However, Pauling who laid the foundations for the nature of the chemical bond worked with Arnold Sommerfeld, Niels Bohr, Erwin Schrödinger



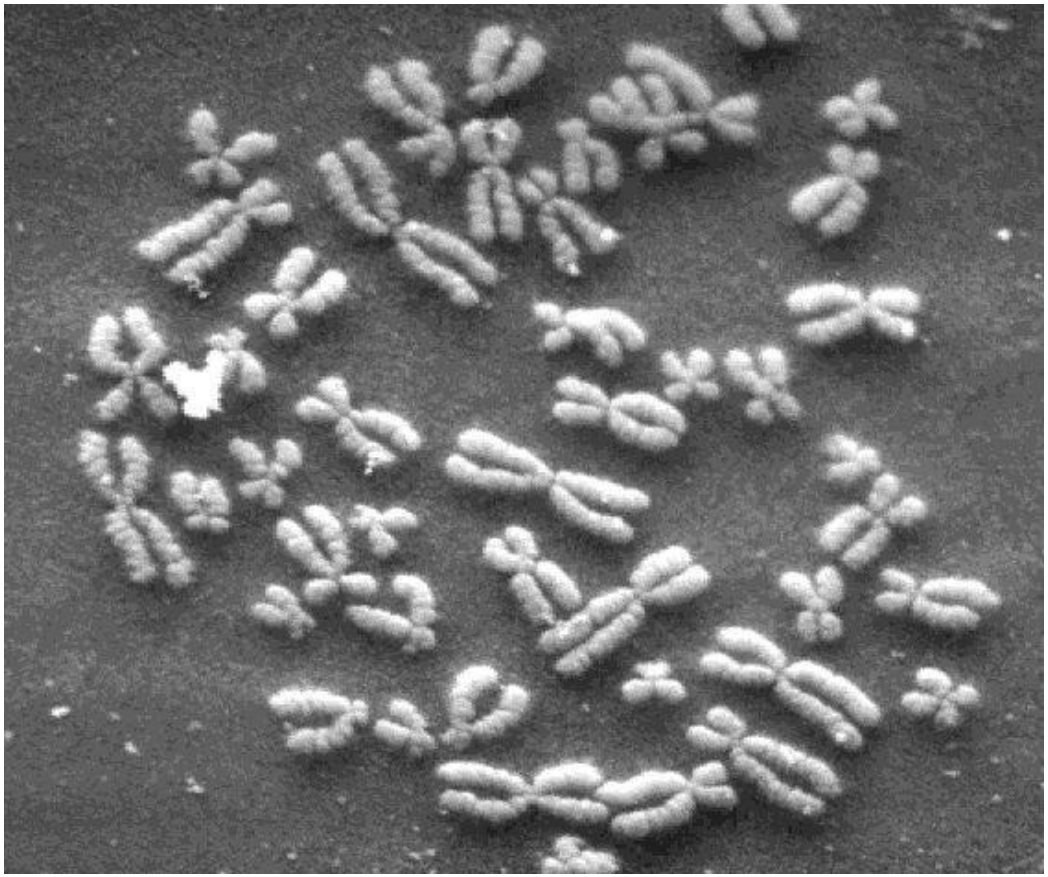
Who were all physicists and were at the foundation of Quantum Mechanics.


In Zurich, he heard of the valence-bond model of Walter Heitler and Fritz London.

So Quantum Chemistry is Quantum Mechanics applied to molecules

After WW-II, Pauling became interested in the structure of DNA.

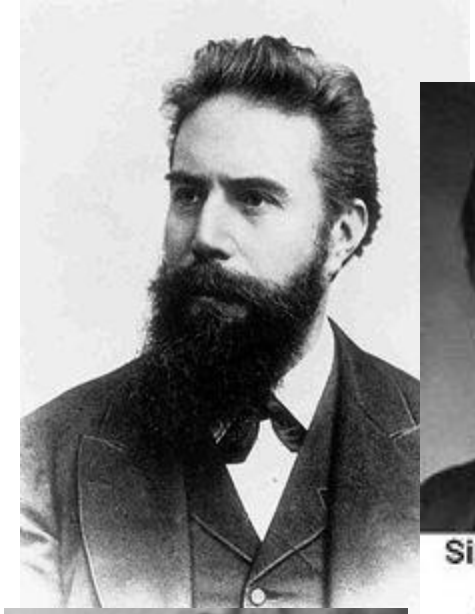
Since DNA is at the heart of life, this could be called biology. It is generally known as molecular biology.

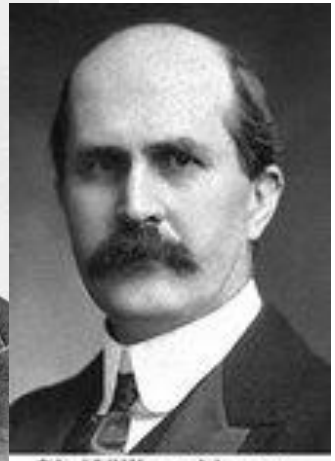


However, somebody else beat him to it.

The best way to look at atomic structure is via X-ray diffraction, the basis for X-ray diffraction was made by physicists

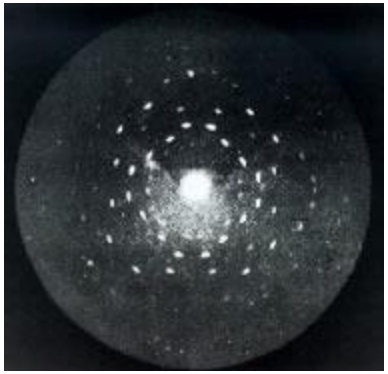
1895: discovery of X-rays by Wilhelm Röntgen





Sir William Henry Bragg
(1862 - 1942)

1912: discovery of X-ray diffraction by Max von Laue
(other contributors Ewald, Sommerfeld)

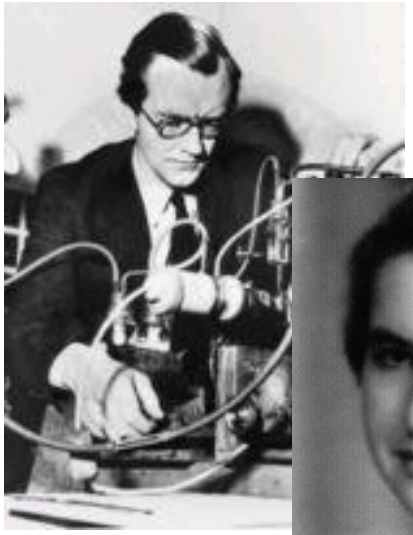


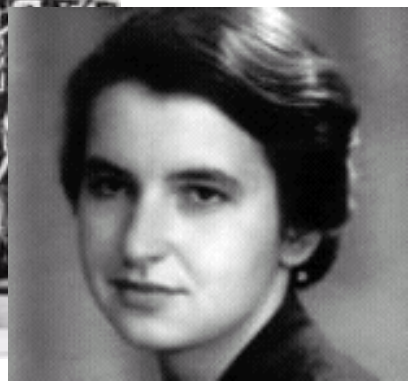
William Lawrence Bragg
(1890 - 1971)

1913: interpretation by William and Lawrence Bragg

Data analysis was not always that straightforward:

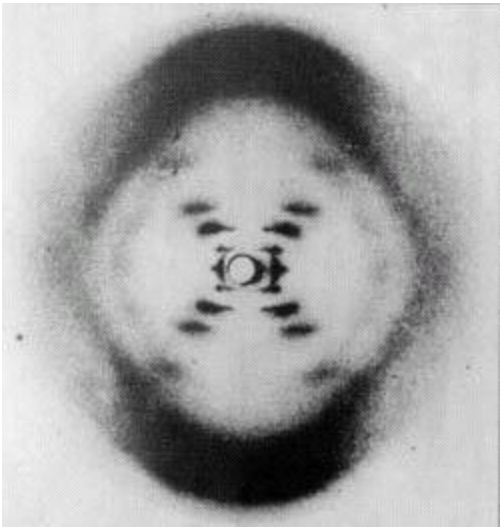
The Experimentalists (London):

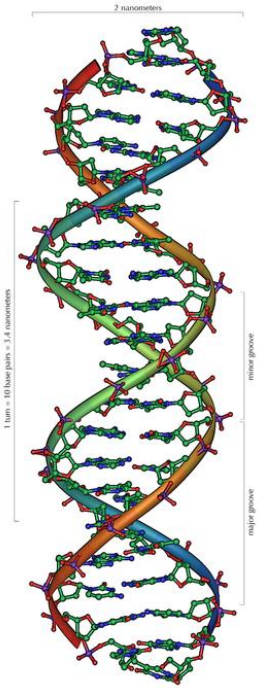




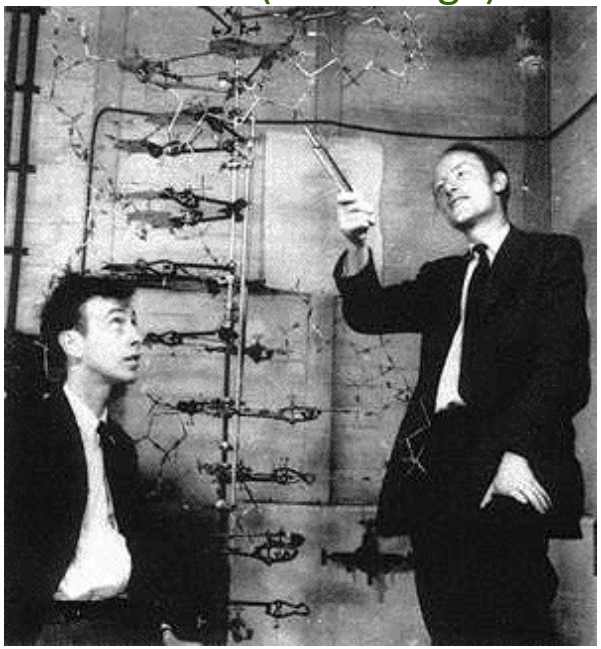
Rosalind Franklin
Biophysicist

Maurice Wilkins
Physicist





The theorists (Cambridge):

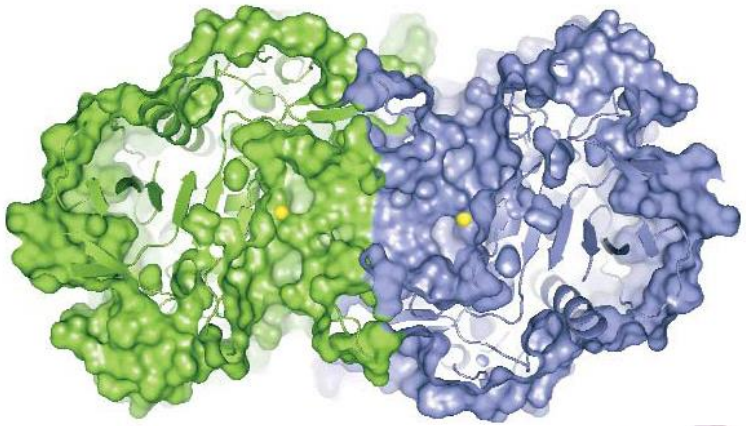


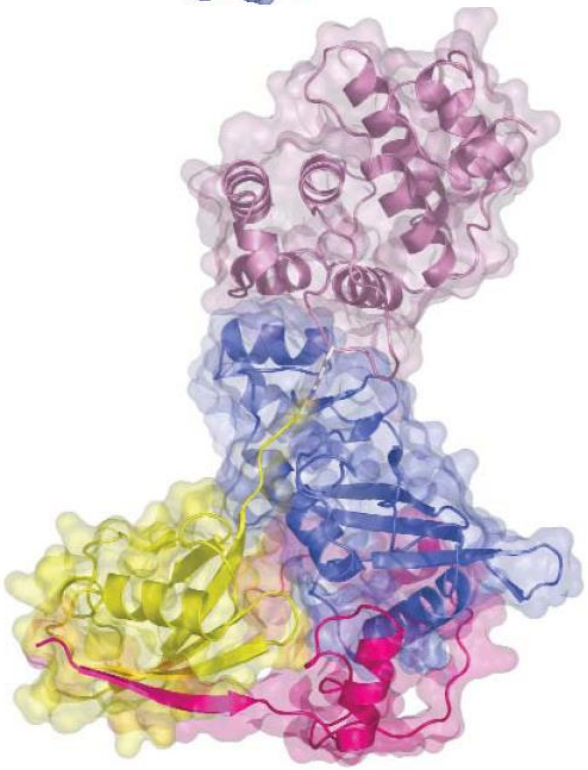
James Watson
Biologist

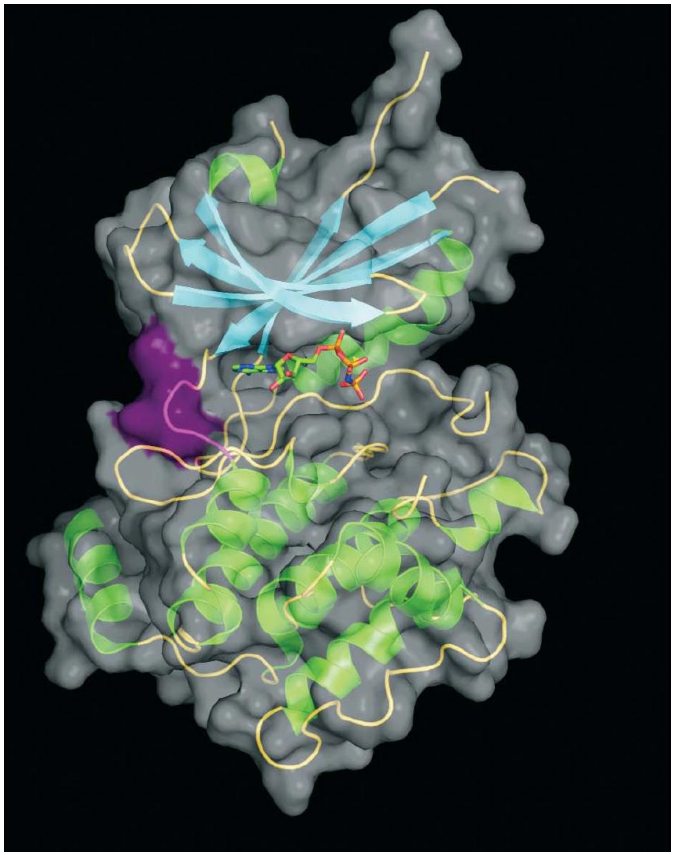
Francis Crick
Physicist

Measurement in Fourier space or momentum space

In the end, this field was taken over by biologists





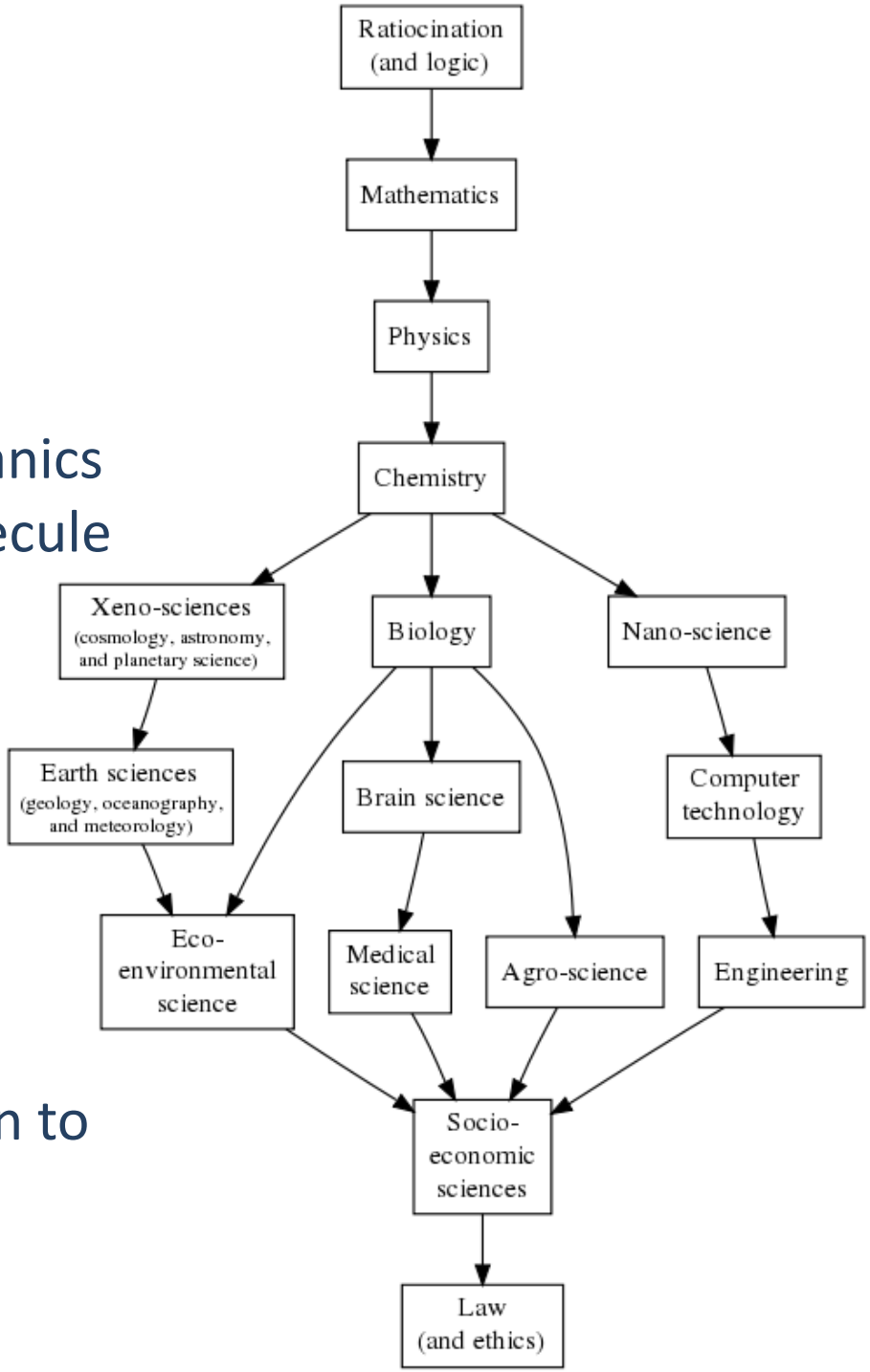


In the end, they are all doing natural philosophy, they just think about it differently.

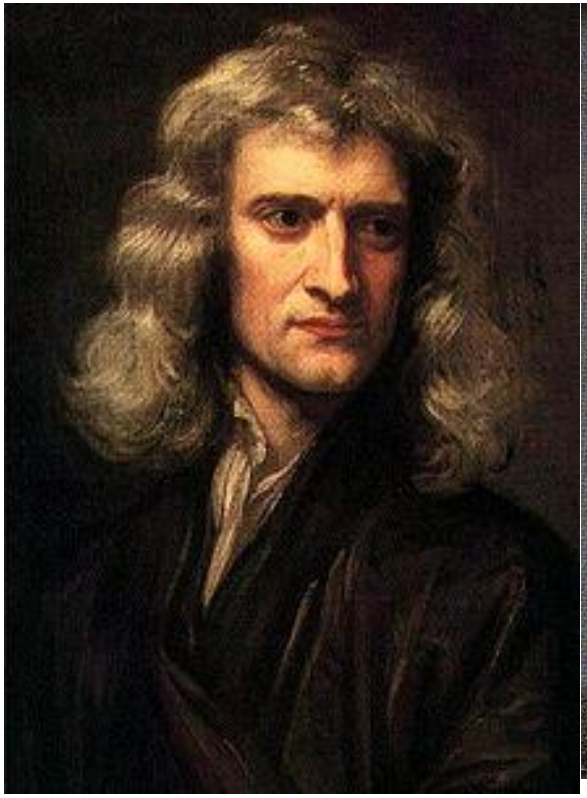
DNA=large molecule:
Physicists see atoms, quantum mechanics and work their way up to a large molecule (biophysics)

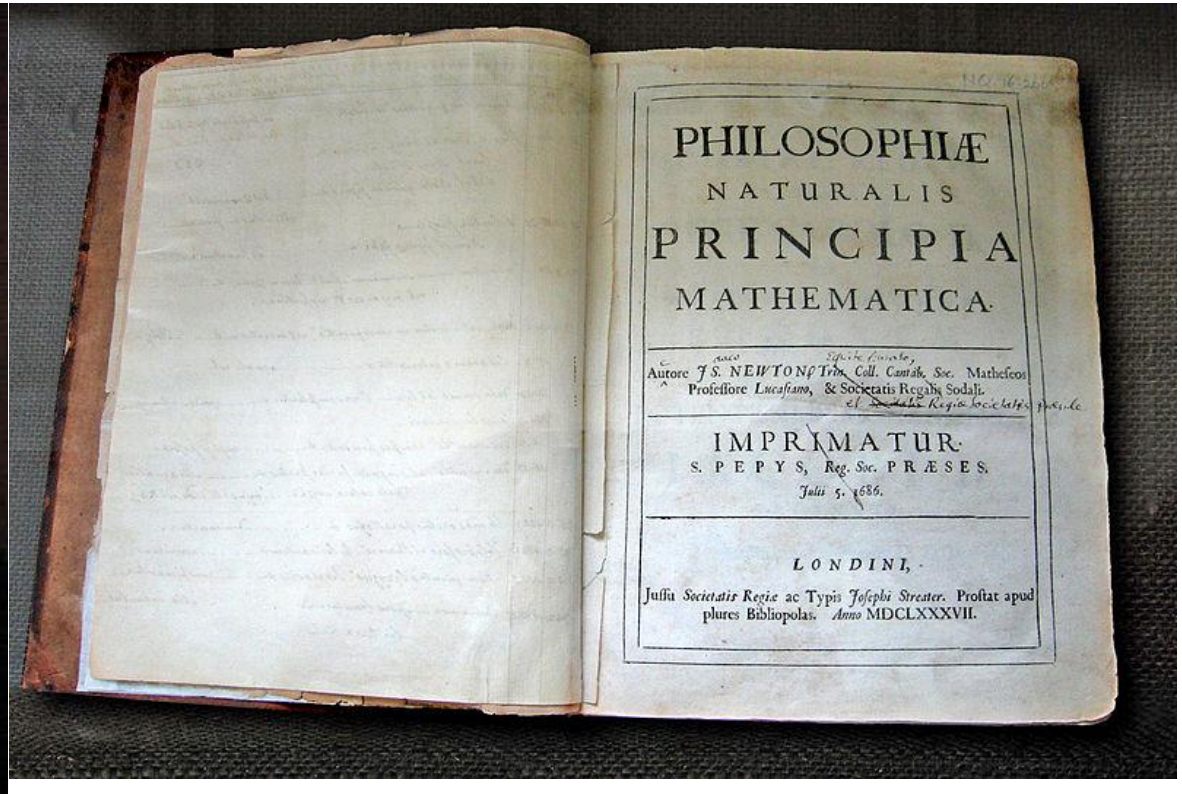
Chemists see molecules and their reactions
(biochemistry)

Biologists see cells, and basic building blocks of life and work their way down to molecules
(molecular biology)



Isaac Newton’s definition of physics





PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore JS. NEWTONO Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

Philosophiæ Naturalis Principia Mathematica, (Mathematical Principles of Natural Philosophy), or simply the ***Principia*** (1687)

So physics is natural philosophy based on mathematical principles

A physicist sees a natural phenomenon and wants to understand the basic underlying principles.

Understanding for a physicist means setting up a mathematical model/theory that fits real life/experiment

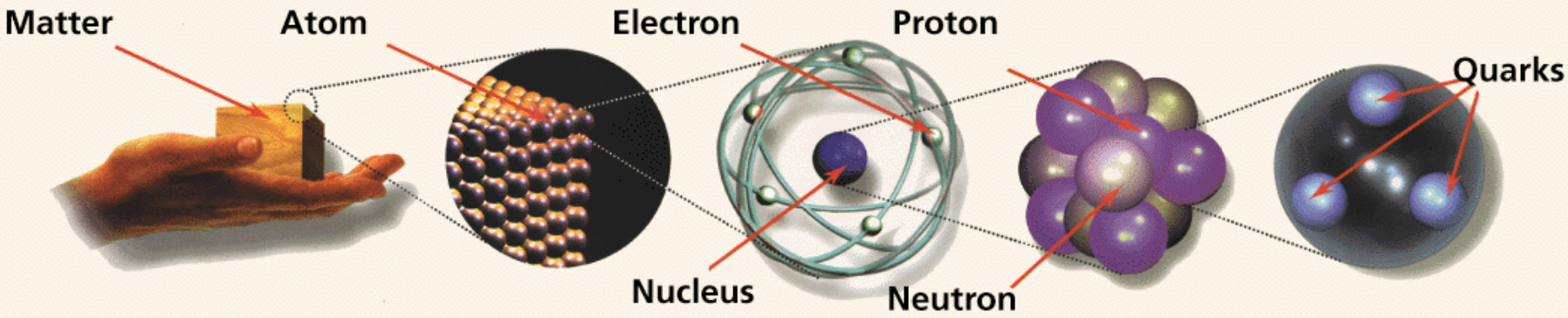
- A conceptual model is a good starting point, but it does not satisfy a physicist (for example, Darwin's theory of evolution is not a good physics model)
- A phenomenological model also does not make a physicists happy (for example, reaction dynamics in chemistry, although extremely useful, do not satisfy a physicist).

Why is physics so hard (mathematically speaking)?

Because physicists do ‘simple’ things, but since they do it based on fundamental principles/laws, it get very complicated

For example, the structure of particles:

- Just quarks, electrons, certainly not as difficult as DNA or a living cell



Matter Particles

All ordinary particles belong to this group

These particles existed just after the Big Bang. Now they are found only in cosmic rays and accelerators.

LEPTONS

FIRST FAMILY	**Electron** Responsible for electricity and chemical reactions; it has a charge of –1	**Électron neutrino** Particle with no electric charge, and possibly no mass; billions fly through your body every second
SECOND FAMILY	**Muon** A heavier relative of the electron; it lives for two-millionths of a second	**Muon neutrino** Created along with muons when some particles decay
THIRD FAMILY	**Tau** heavier still; it is extremely unstable. It was discovered in 1975	**Tau neutrino** Not yet discovered but believed to exist

QUARKS

Up Has an electric charge of plus two-thirds; protons contain two, neutrons contain one	**Down** Has an electric charge of minus one-third; protons contain one, neutrons contain two
Charm A heavier relative of the up; found in 1974	**Strange** A heavier relative of the down; found in 1974
Top Heavier still, found in 1995	**Bottom** Heavier still; measuring bottom quarks is an important test of electroweak theory

Force Particles

These particles transmit the four fundamental forces of nature although gravitons have so far not been discovered

Gluons
Carriers of the strong force between quarks

Felt by: quarks

The explosive release of nuclear energy is the result of the strong force

Photons
Particles that make up light; they carry the electromagnetic force

Felt by: quarks and charged leptons

Electricity, magnetism and chemistry are all the results of the electromagnetic force

Intermediate vector bosons
Carriers of the weak force

Felt by: quarks and leptons

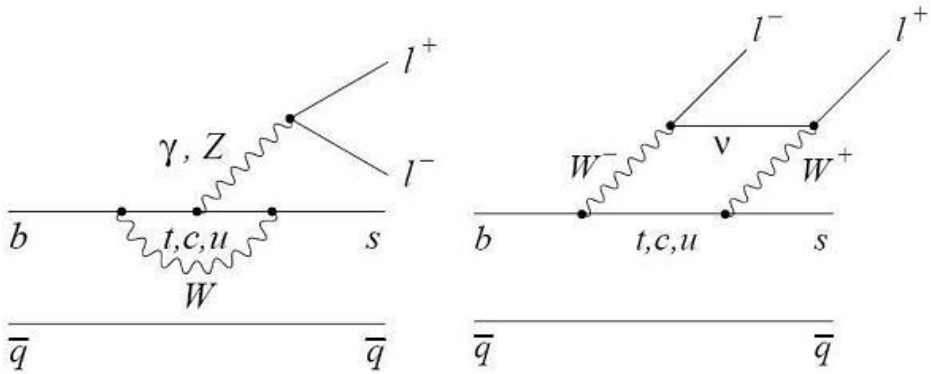
Some forms of radioactivity are the result of the weak force

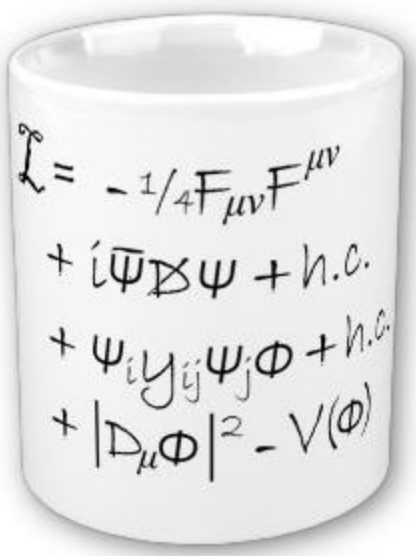
Gravitons
Carriers of gravity

Felt by: all particles with mass

All the weight we experience is the result of the gravitational force

Of course, that's a pretty poster
However, for a physicist to say (s)he knows the standard model, because (s)he memorized the poster, is like





$$\mathcal{L}_{GWS} = \sum_f (\bar{\Psi}_f (i\gamma^\mu \partial\mu - m_f)\Psi_f - eQ_f \bar{\Psi}_f \gamma^\mu \Psi_f A_\mu) +$$

$$+ \frac{g}{\sqrt{2}} \sum_i (\bar{a}^i_L \gamma^\mu b^i_L W^+_\mu + \bar{b}^i_L \gamma^\mu a^i_L W^-_\mu) + \frac{g}{2c_w} \sum_f \bar{\Psi}_f \gamma^\mu (I^3_f - 2s^2_w Q_f - I^3_f \gamma_5) \Psi_f Z_\mu +$$

$$- \frac{1}{4} |\partial_\mu A_\nu - \partial_\nu A_\mu - ie(W^-_\mu W^+_\nu - W^+_\mu W^-_\nu)|^2 - \frac{1}{2} |\partial_\mu W^+_\nu - \partial_\nu W^+_\mu +$$

$$- ie(W^+_\mu A_\nu - W^+_\nu A_\mu) + ig' c_w (W^+_\mu Z_\nu - W^+_\nu Z_\mu|^2 +$$

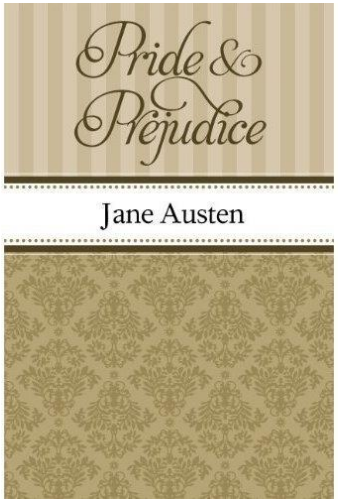
$$- \frac{1}{4} |\partial_\mu Z_\nu - \partial_\nu Z_\mu + ig' c_w (W^-_\mu W^+_\nu - W^+_\mu W^-_\nu)|^2 +$$

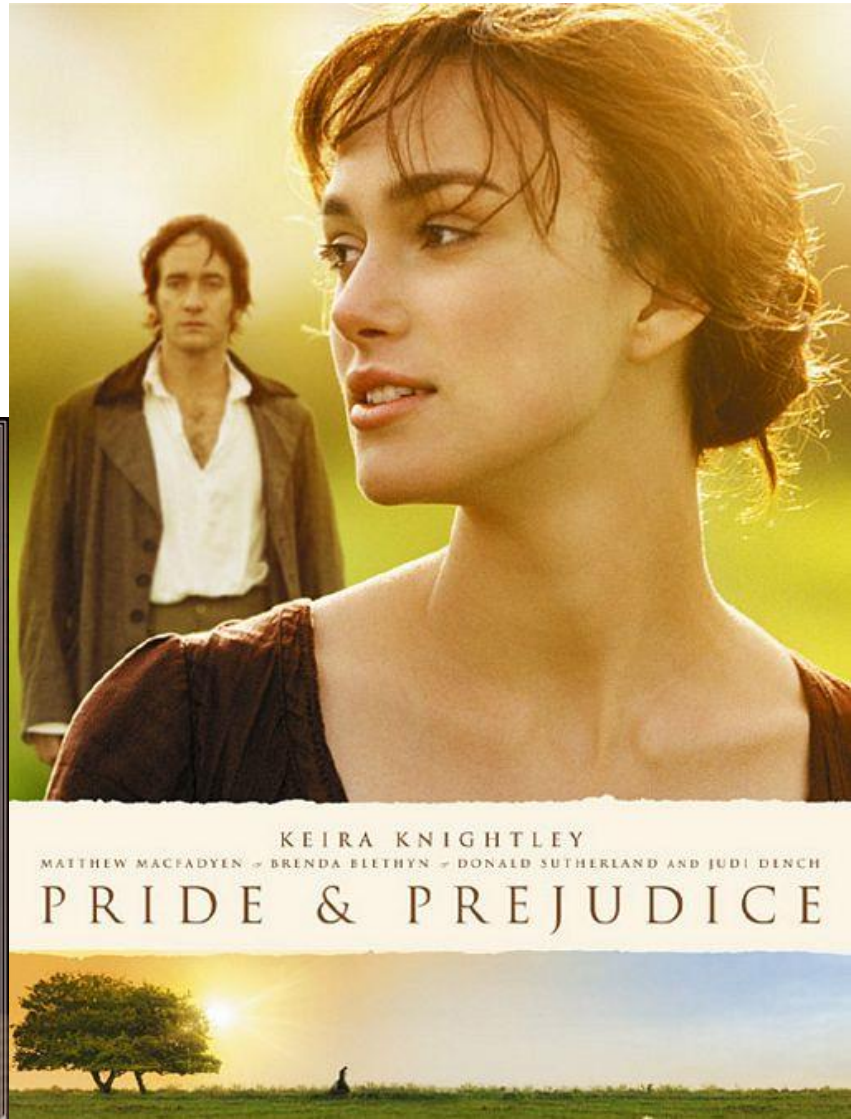
$$- \frac{1}{2} M^2_\eta \eta^2 - \frac{g M^2_\eta}{8 M_W} \eta^3 - \frac{g'^2 M^2_\eta}{32 M_W} \eta^4 + |M_W W^+_\mu + \frac{g}{2} \eta W^+_\mu|^2 +$$

$$+ \frac{1}{2} |\partial_\mu \eta + i M_Z Z_\mu + \frac{ig}{2c_w} \eta Z_\mu|^2 - \sum_f \frac{g}{2} \frac{m_f}{M_W} \bar{\Psi}_f \Psi_f \eta$$

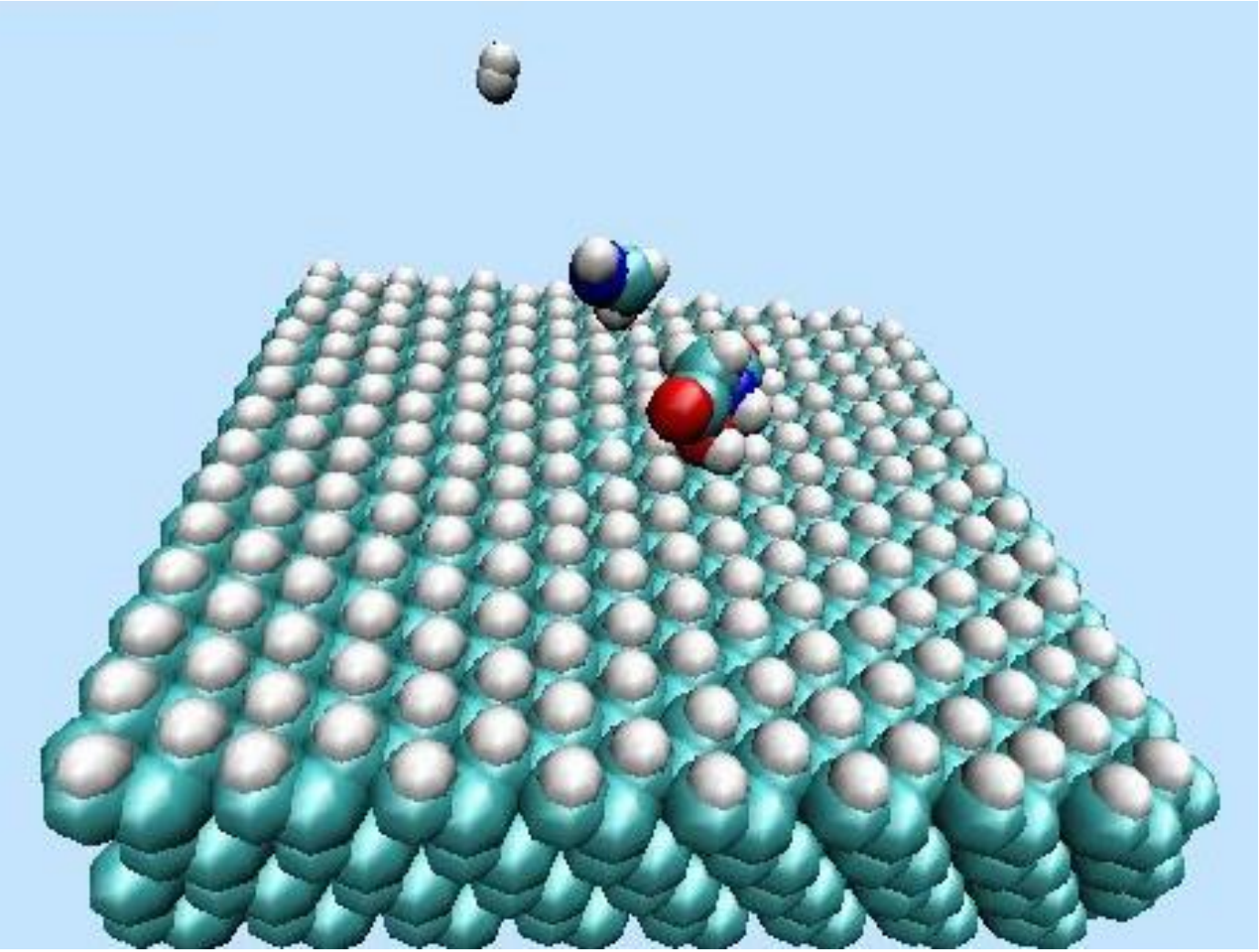
Don't worry we won't do anything of this sort…

Is like an English major saying the know Jane Austen, when (s)he has just seen the movie



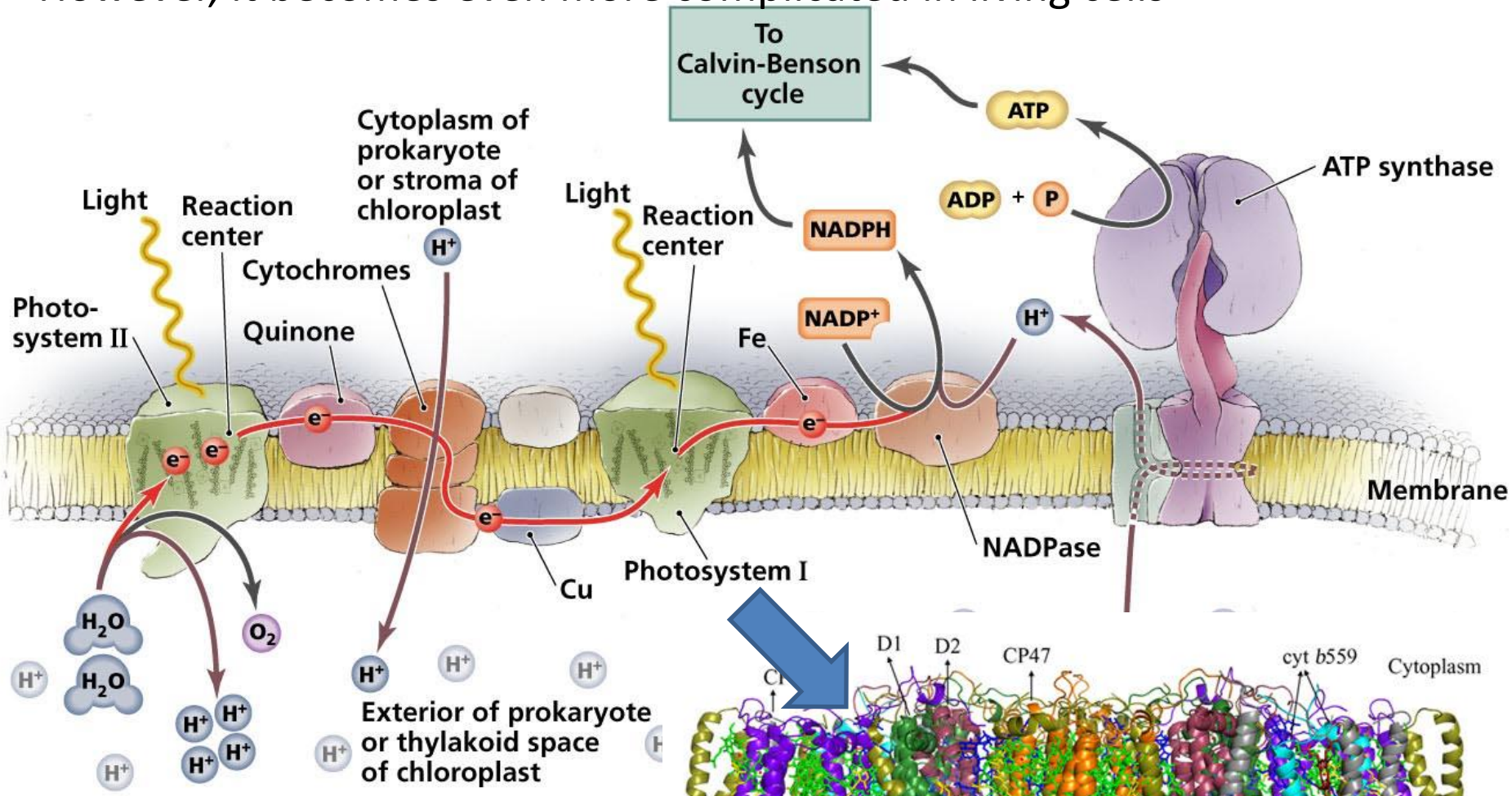


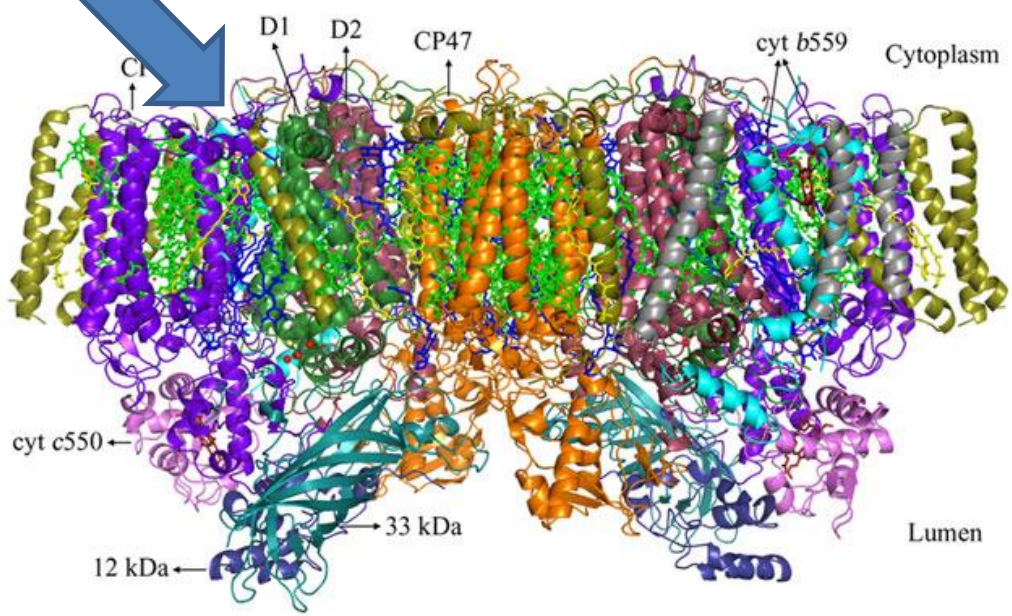
However, chemical reactions are more than just quantum chemistry: there is kinetics (surfaces, temperature, pressure, activation energies), thermodynamics, bond breaking, catalysts, energy landscapes, etc



This often requires phenomenology: chemistry

However, it becomes even more complicated in living cells





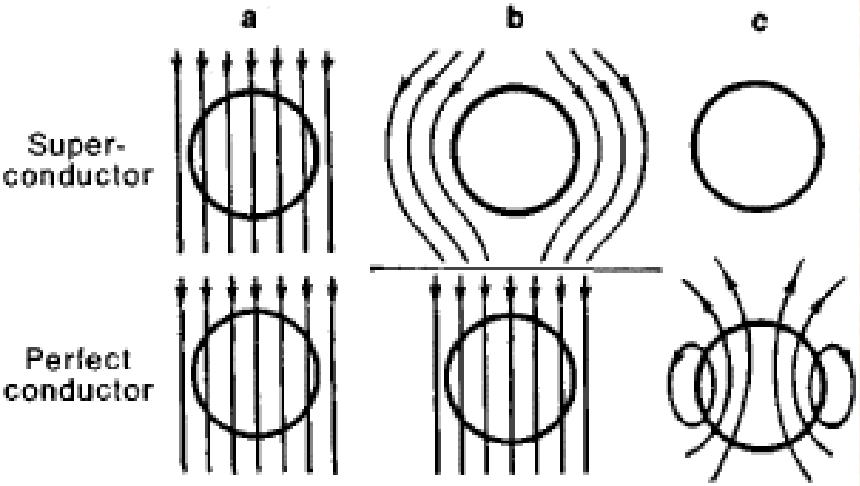
How do plants use sun light to break water and then turn it into sugars?

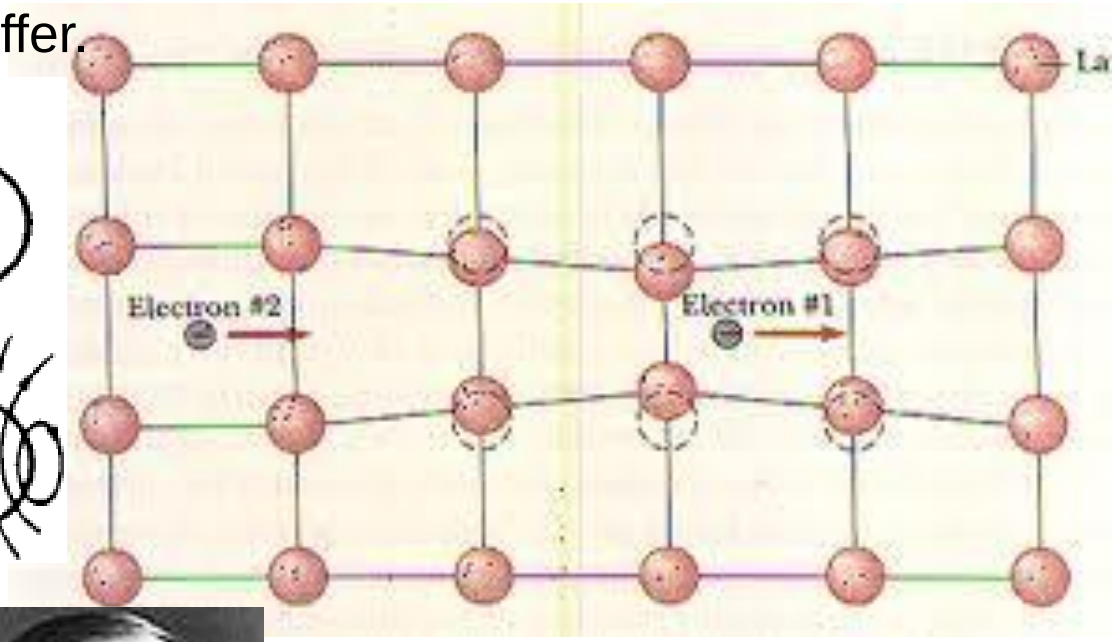
This is not ready yet for a physics bottom-up approach

In physics, understanding how interaction can lead to emerging phenomena is a very difficult problem

Superconductivity: BCS theory, 1972 Nobel prize

Bardeen Cooper and Schrieffer.

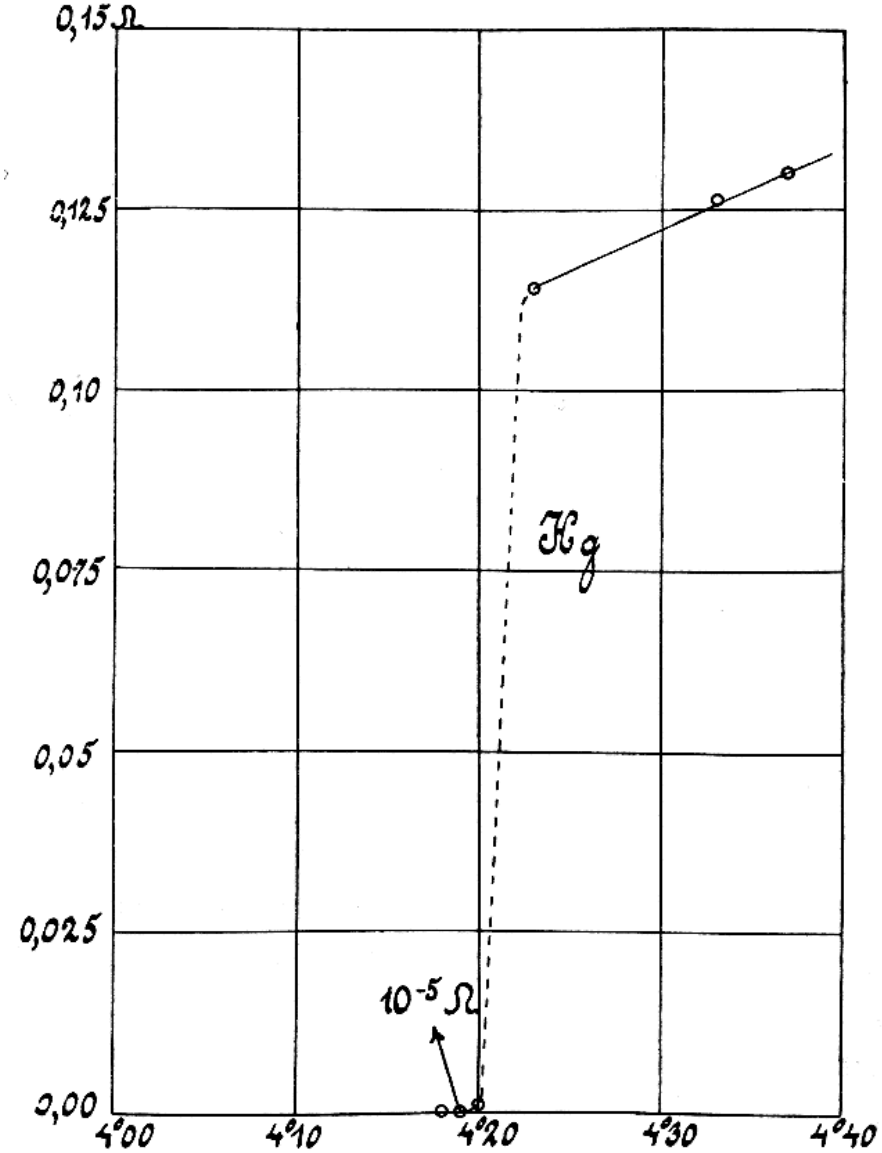




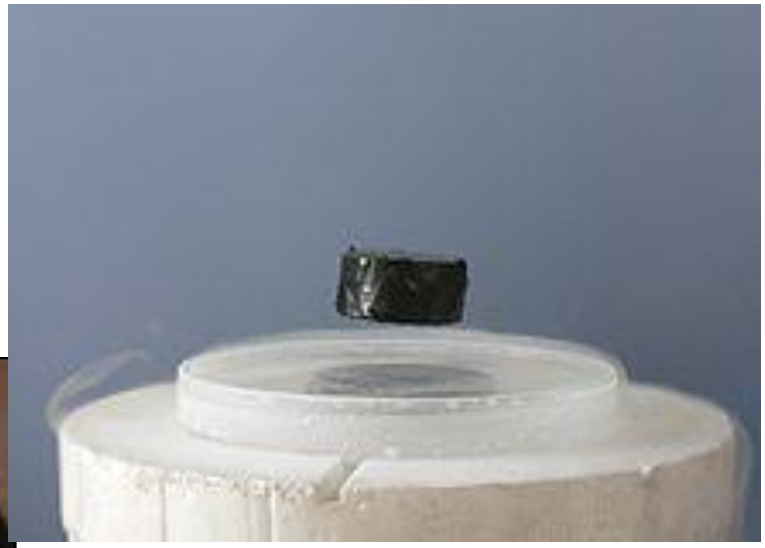
Discovery of superconductivity

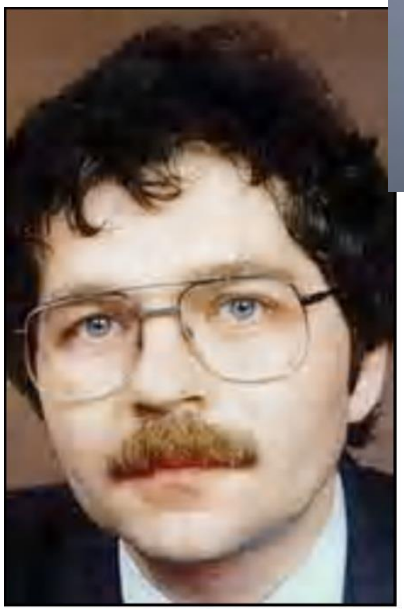
Kamerlingh Onnes in Leiden
in 1911
Mercury (Hg), Tc ~ 4 Kelvin
Liquid helium: 4.2 Kelvin

1913, Nobel Prize



Discovery of high-Tc superconductivity
J. G. Bednorz and K. A. Muller
in IBM Zurich
Nobel prize: in 1988
La-Sr-Cu-O, Tc ~ 30 Kelvin





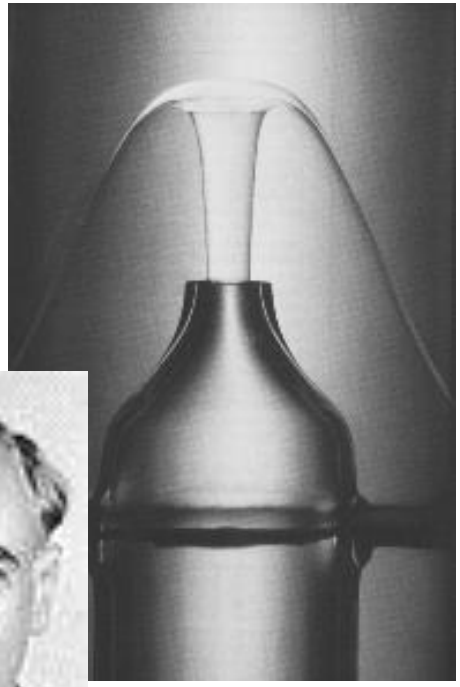
1989, Nobel Prize,

No explanations yet!

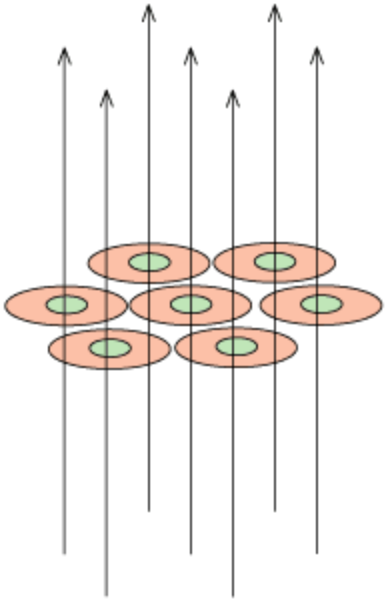
Could revolutionize magnetic levitation trains

Ginzburg, Leggett, and Abrikosov, Nobel prize 2003

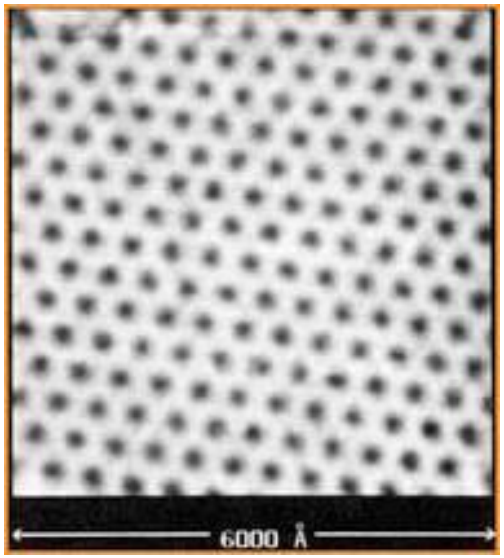
Superfluidity, superconductivity

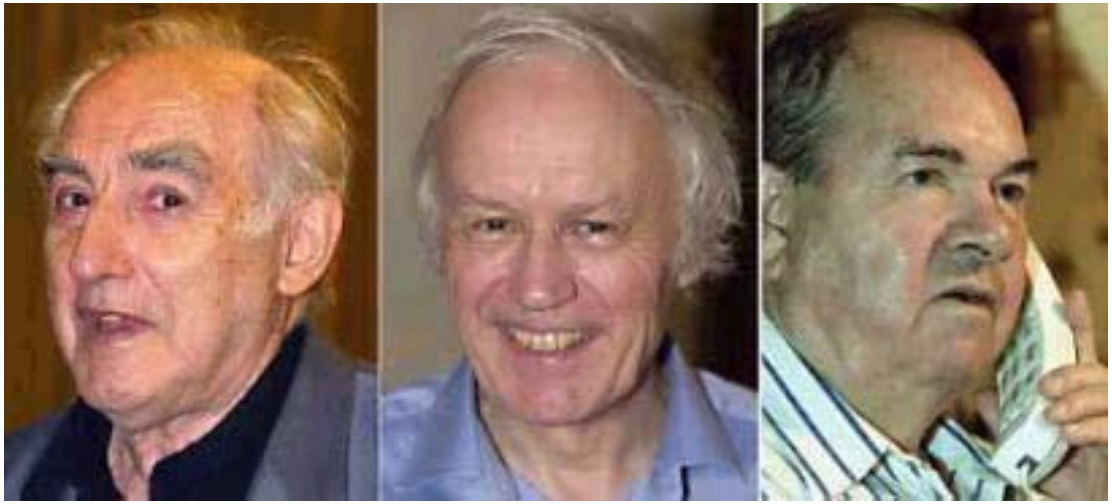


Lev Landau, 1962



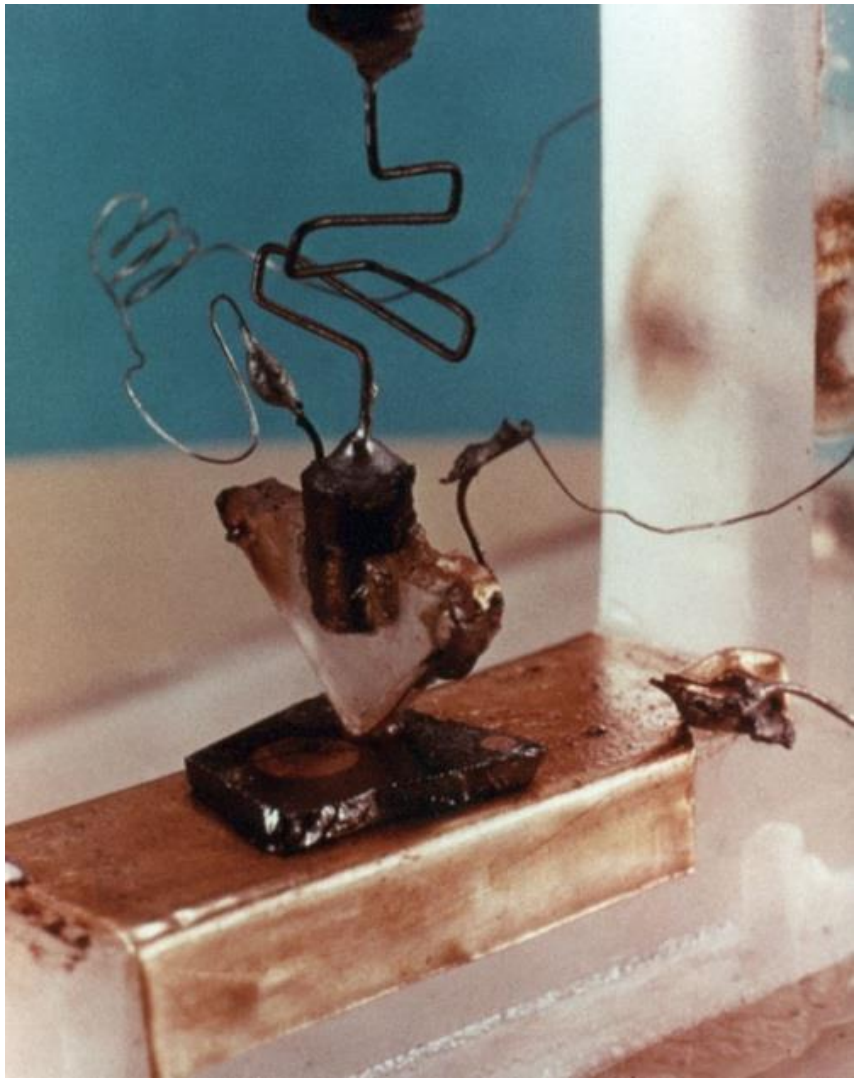
(a)vortex lattice



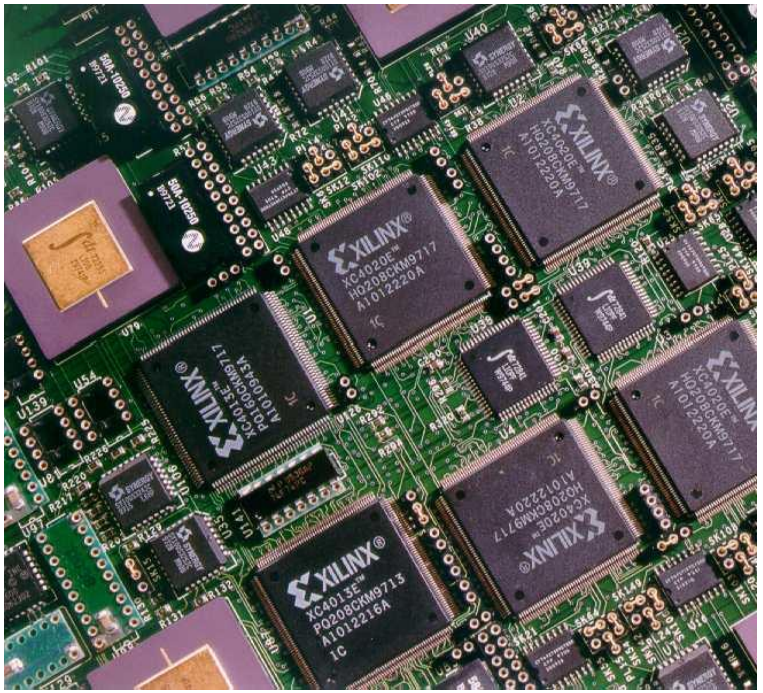


The physicist bottom-up approach also works in other areas

WHAT IS THIS?



Discovery of transistors: Engineering



Then it turns into engineering

First Germanium transistor
in 1947

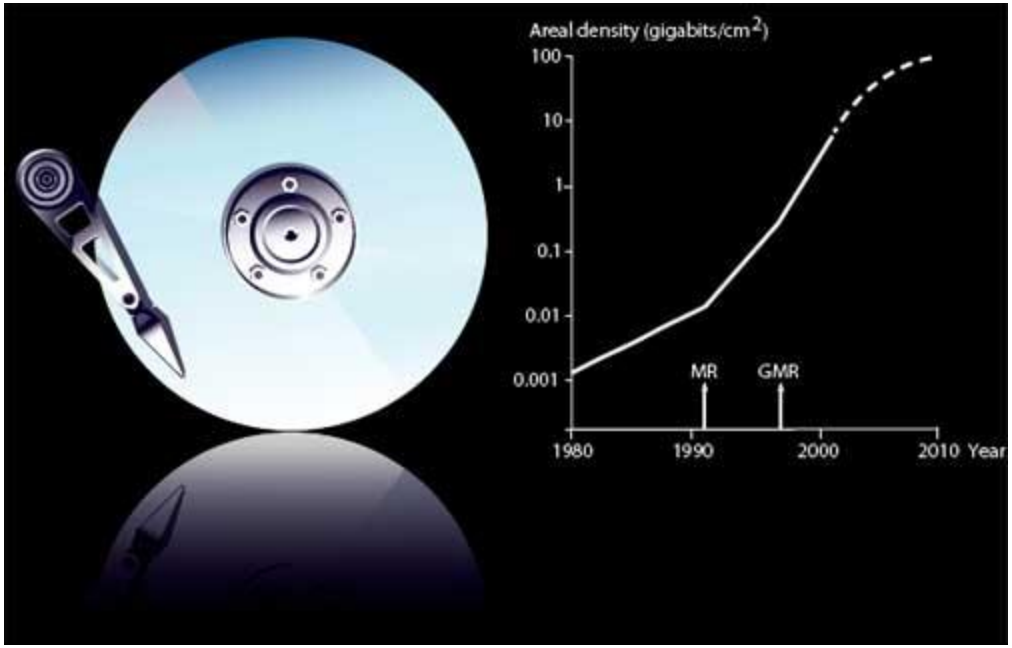
Bardeen, Brattain, Shockley (All physicists)

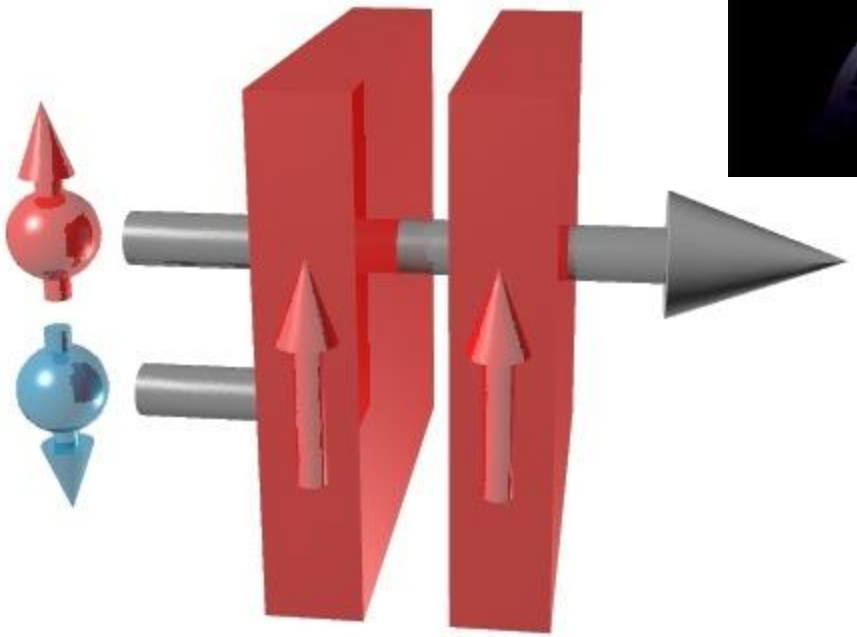
Bell Labs

1956, Nobel prize

Microelectronics: 20th century's greatest achievement in Solid State Physics

Albert Fert and Peter Grunberg, Nobel prize: 2007

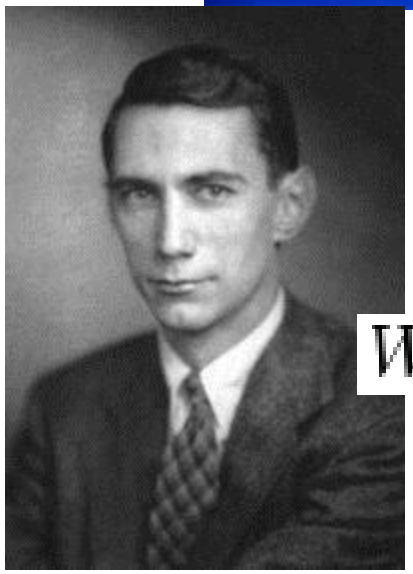




Information theory:
What are the fundamental limits on signal processing

$S = k. \log W$

2nd law of thermodynamics
Entropy



$$W = K \log m.$$

Claude Shannon (1916-2001)

Ludwig Boltzmann (1844-1906)

Does a physics way of thinking work in other areas, or only in the natural sciences?

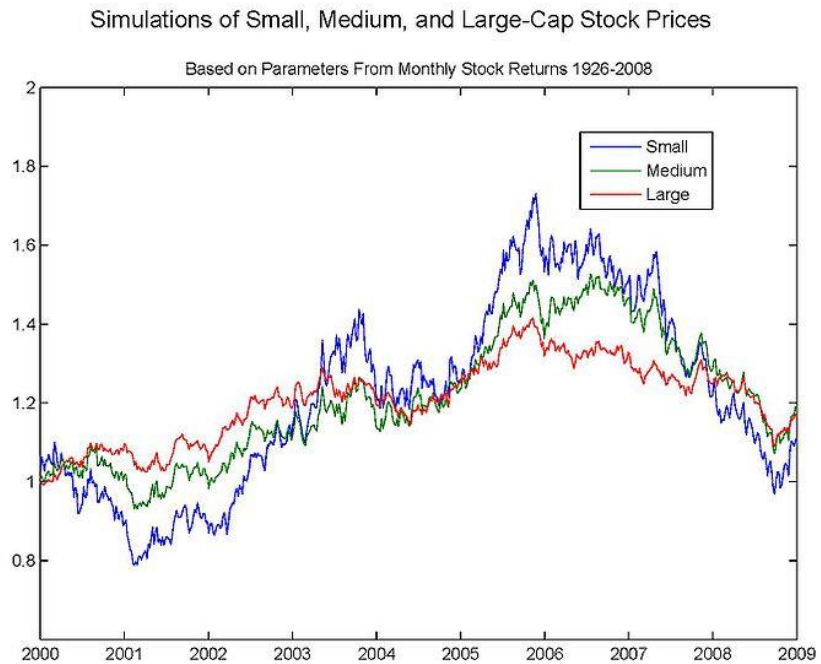
The first Nobel prize winner in economics in 1969 was a physicist: Jan Tinbergen
(he was also Dutch)

He established the field of econometry and set up the first national macroeconomic model

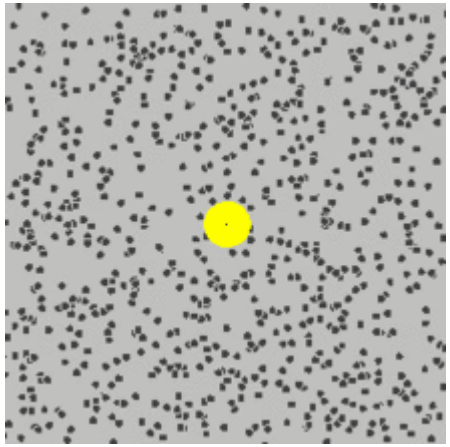
Black-Scholes model of option prizing (Nobel prize 1997)

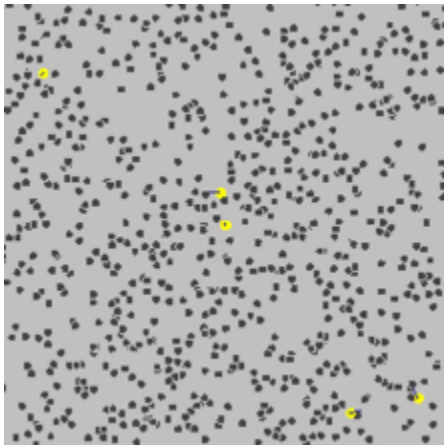
Myron Scholes
Economy

Fischer Black,
Applied mathematics
(switched from physics)

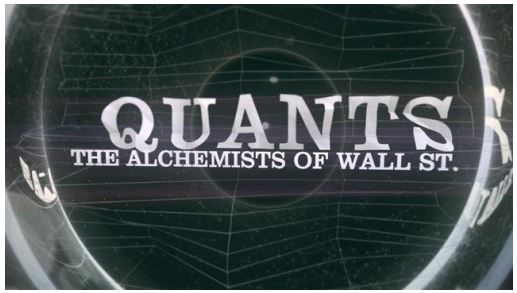


$$\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + rS\frac{\partial V}{\partial S} - rV = 0.$$





Which is related to
Brownian motion
which was explained
by Albert Einstein



Speaking of stocks….

Just for those lovers of useless facts:

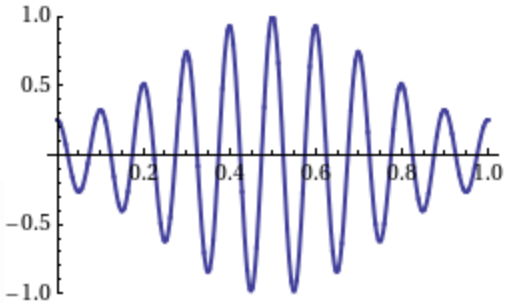
Which was the first publicly traded joint-stock company?

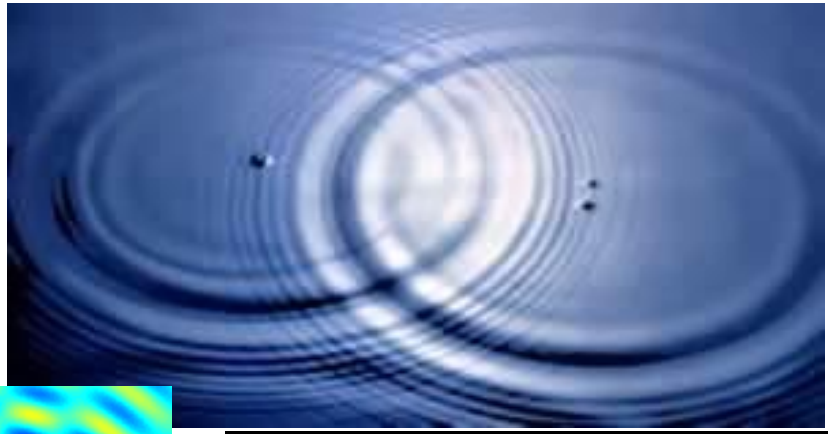
1602: Vereenigde Oost-Indische Compagnie (VOC)
Dutch East India Company
Trading in derivatives, options, etc.

Even pioneered short-selling. Forbidden in 1610

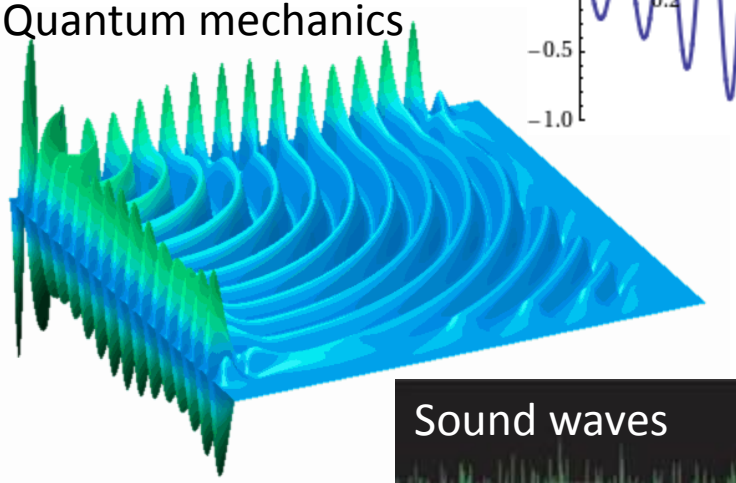
Waves: there everywhere

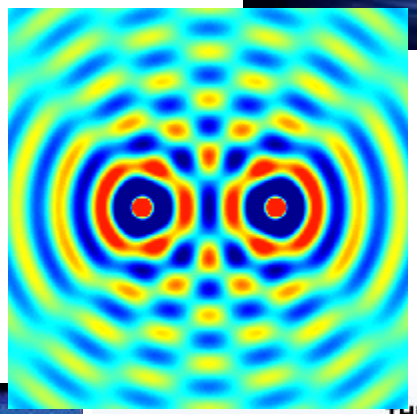
WAVES



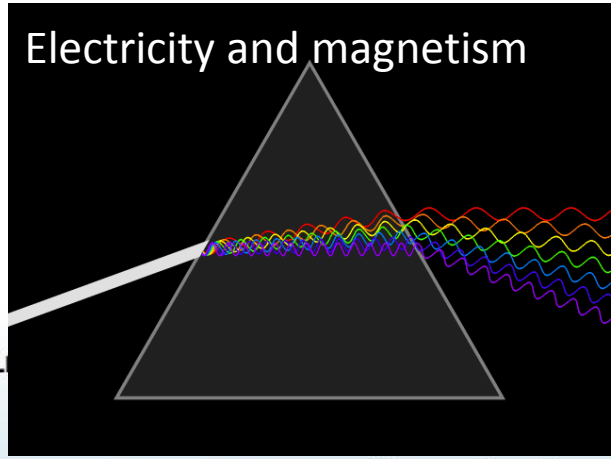


Quantum mechanics

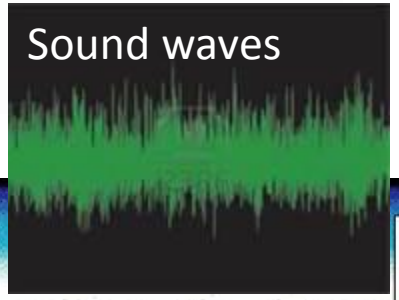


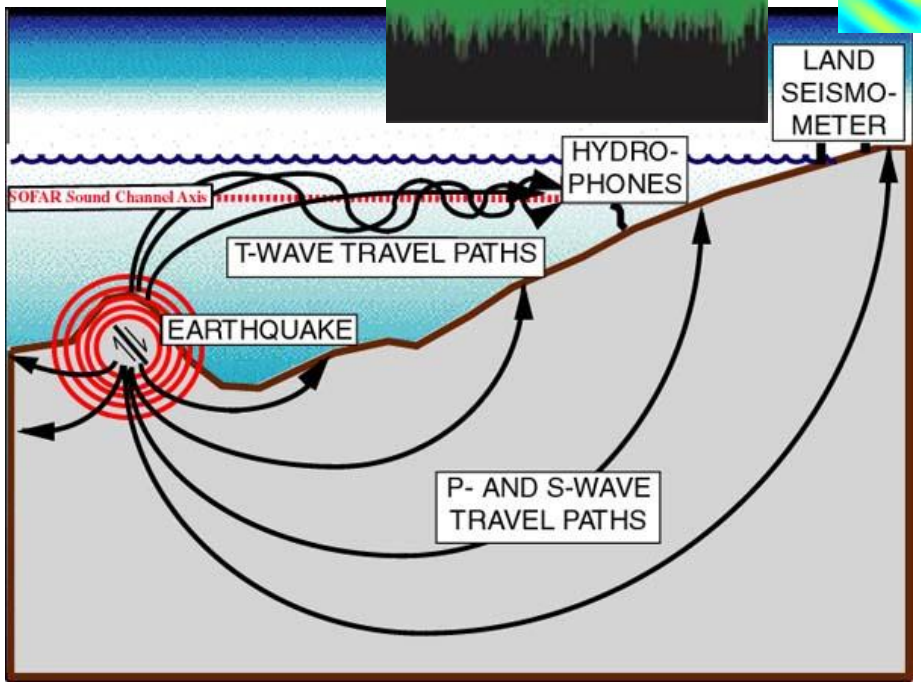


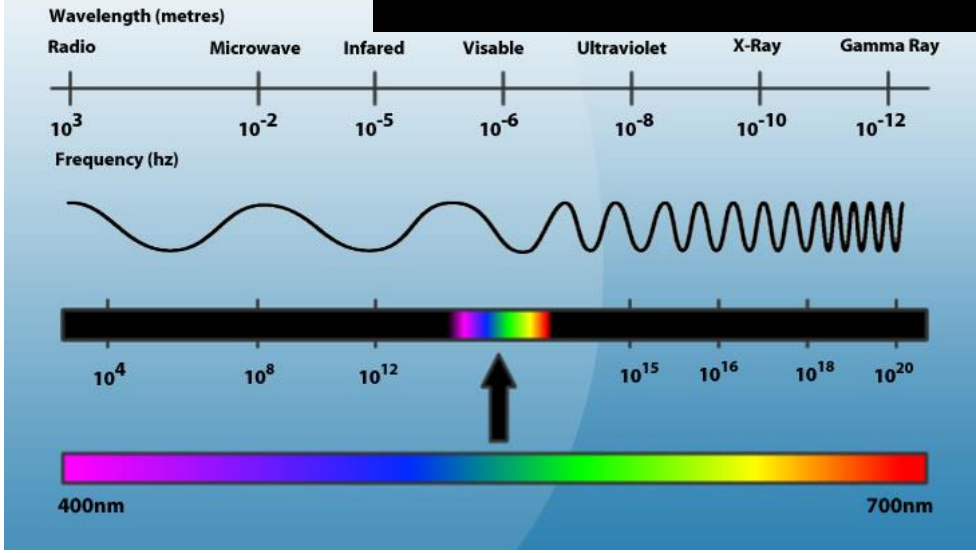
Electricity and magnetism



Sound waves

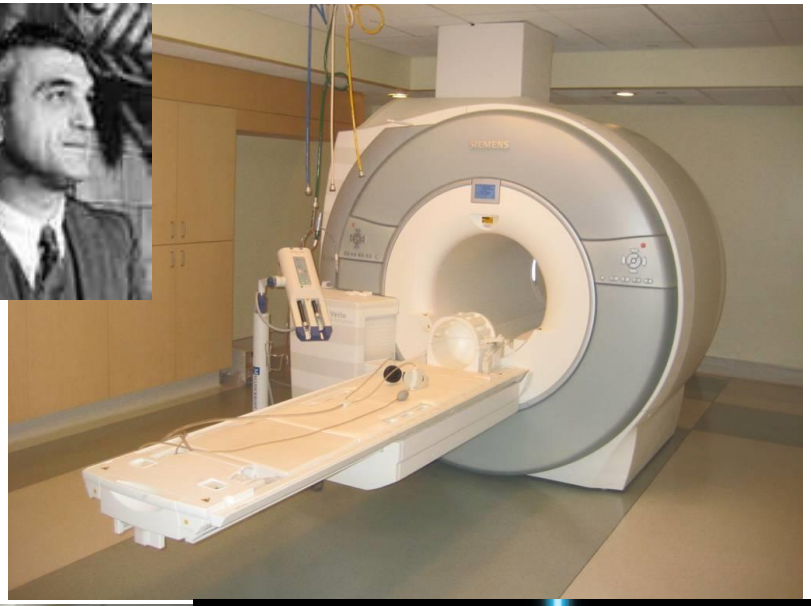




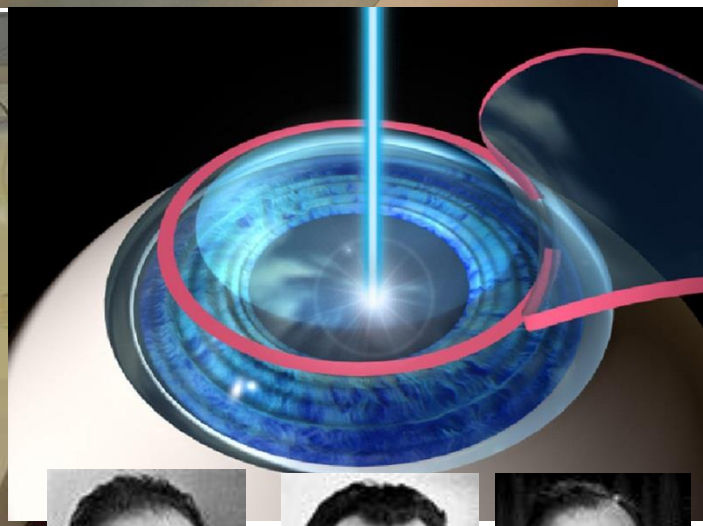


Many medical devices have basic physics breakthroughs at their origin

Bloch



Rontgen



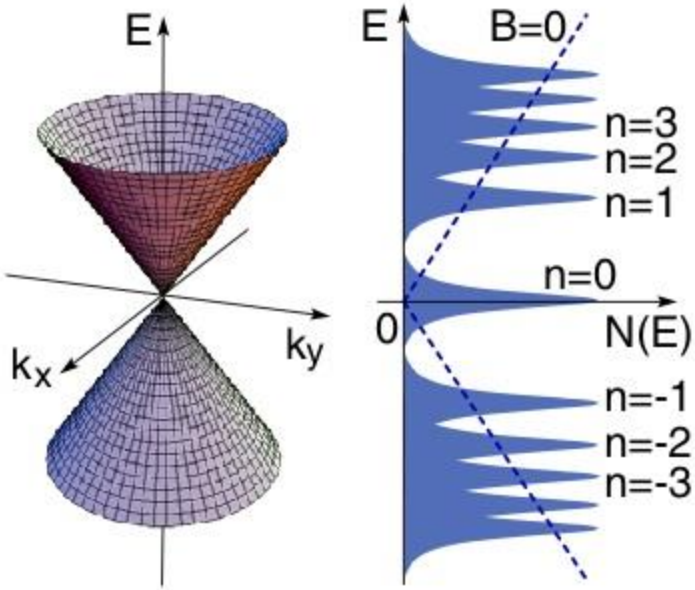
Pierre and Marie Curie

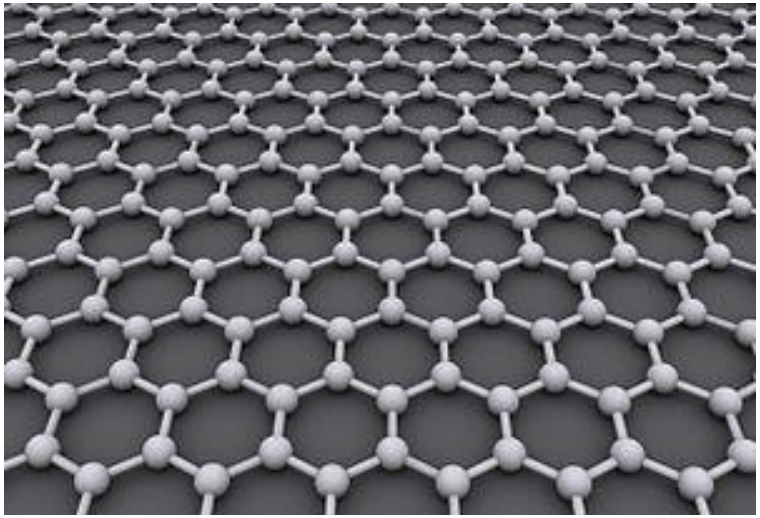
Basov

Prokhorov

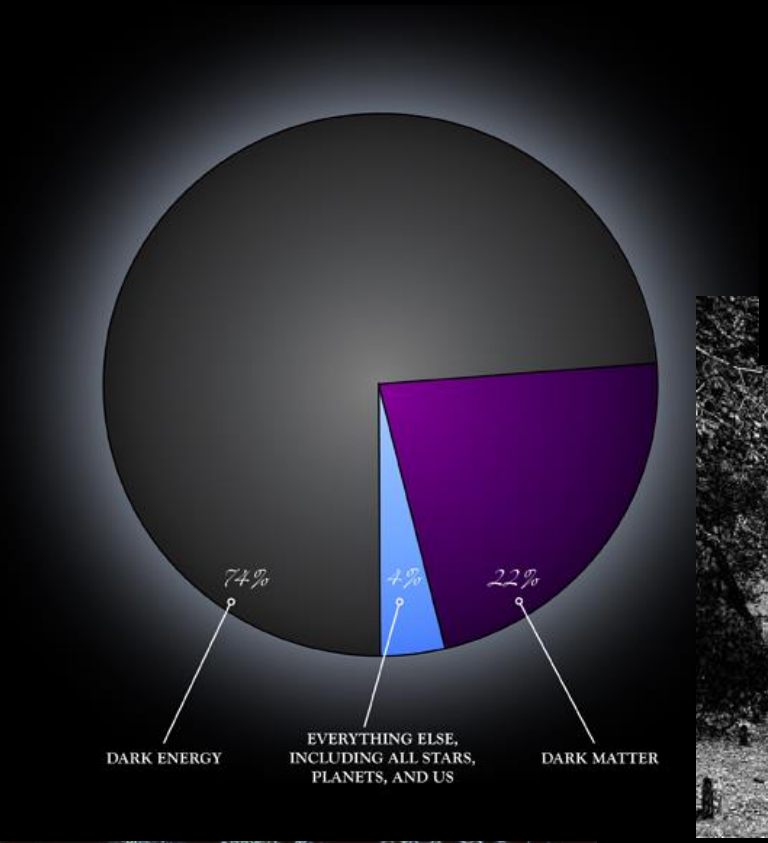
Townes

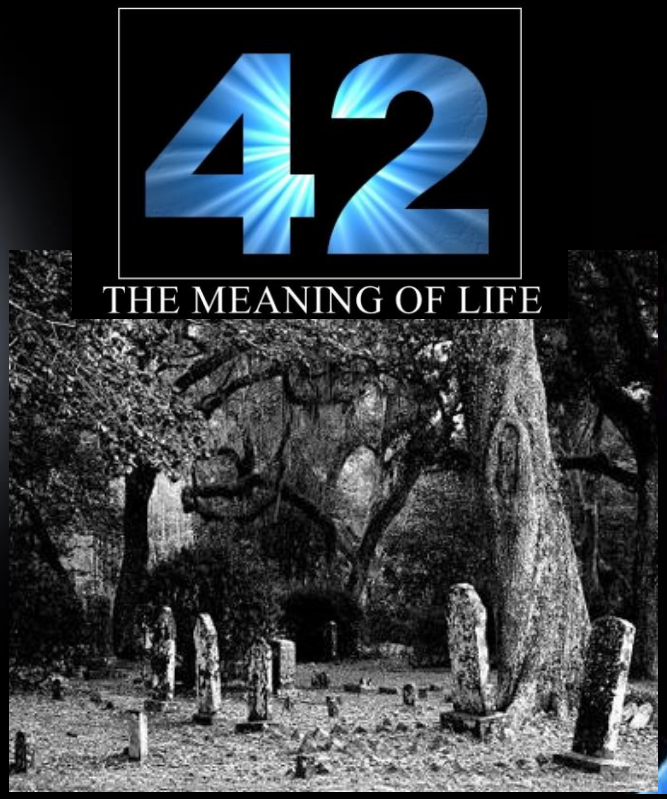
Andre Geim and Konstantin Novoselov Nobel prize: 2010

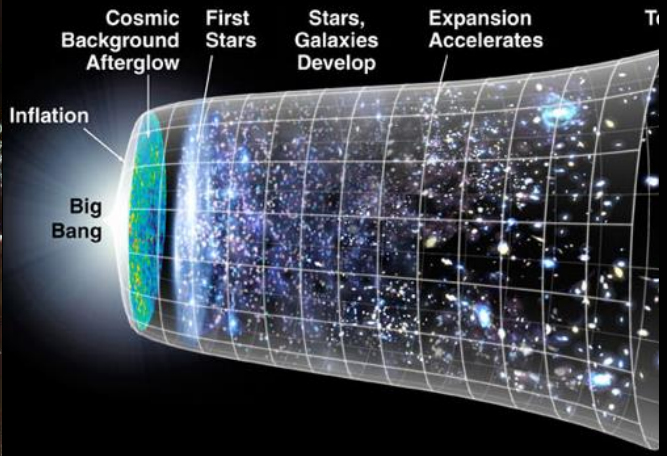




There are still many questions that cannot be answered



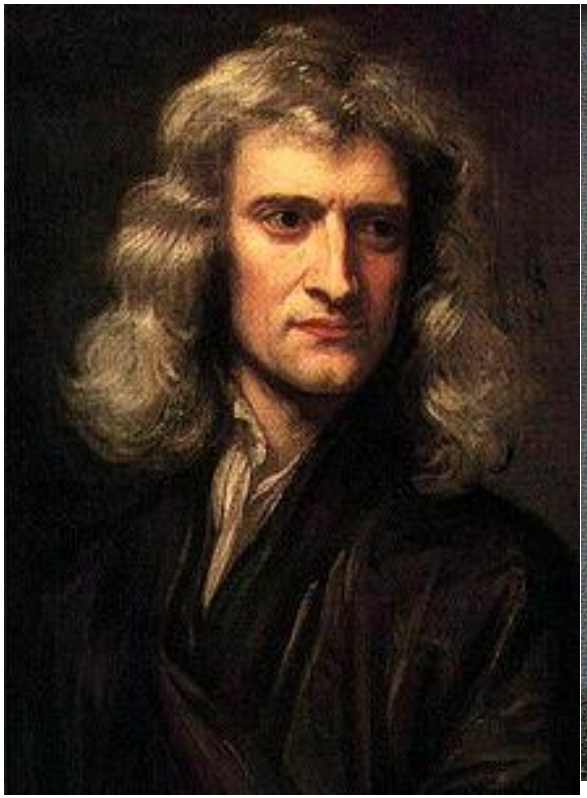


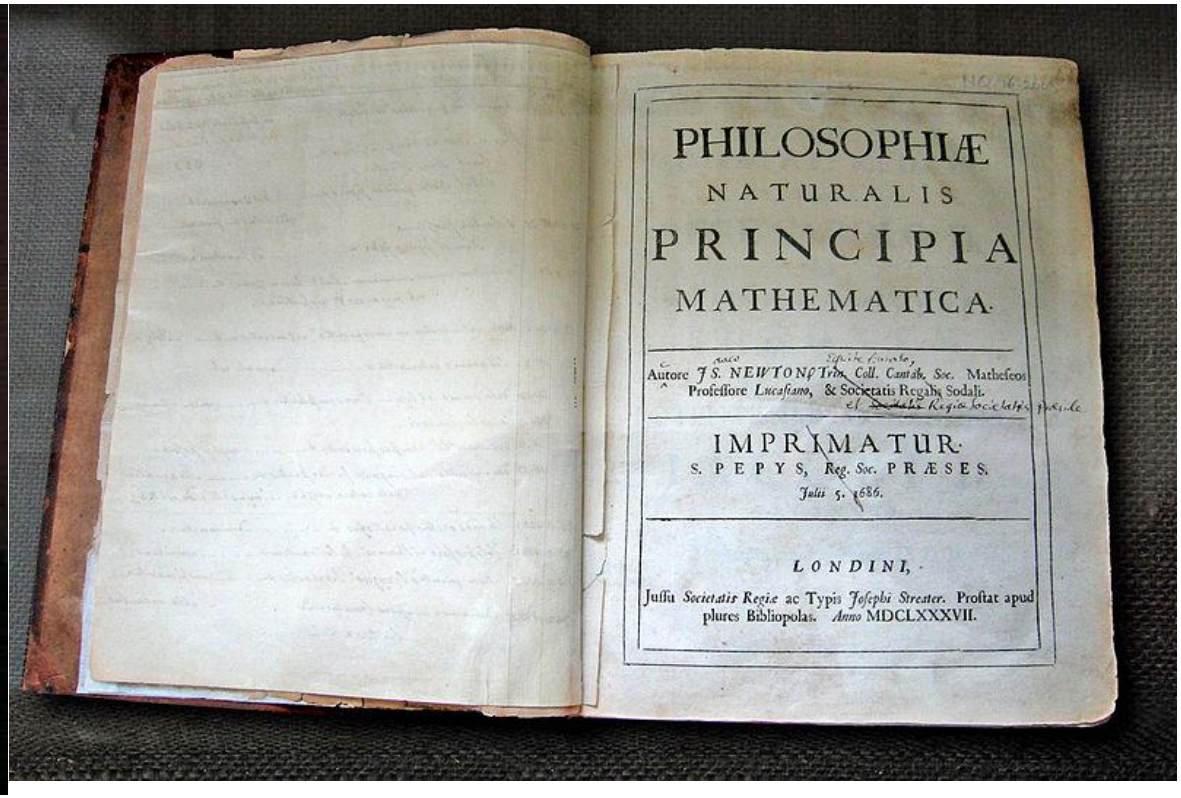


Unfortunately, we are not ready for all of that….

So we start of with classical mechanics

We begin with Newton's three laws





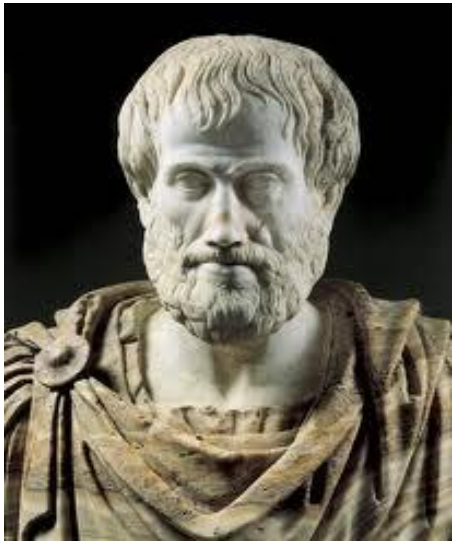
PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

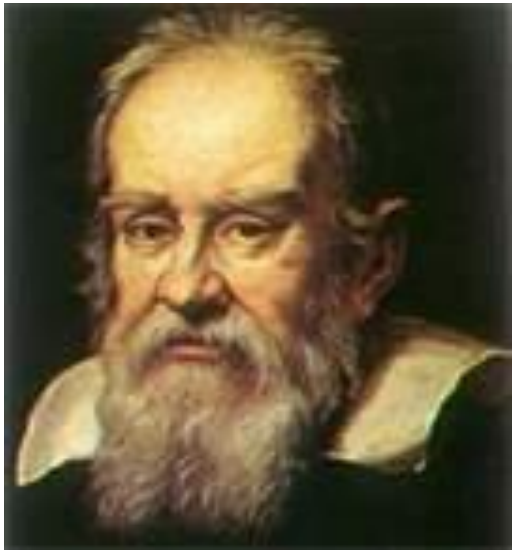
Autore JS. NEWTONO, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

Make excursions back in time to Aristotle and Galileo



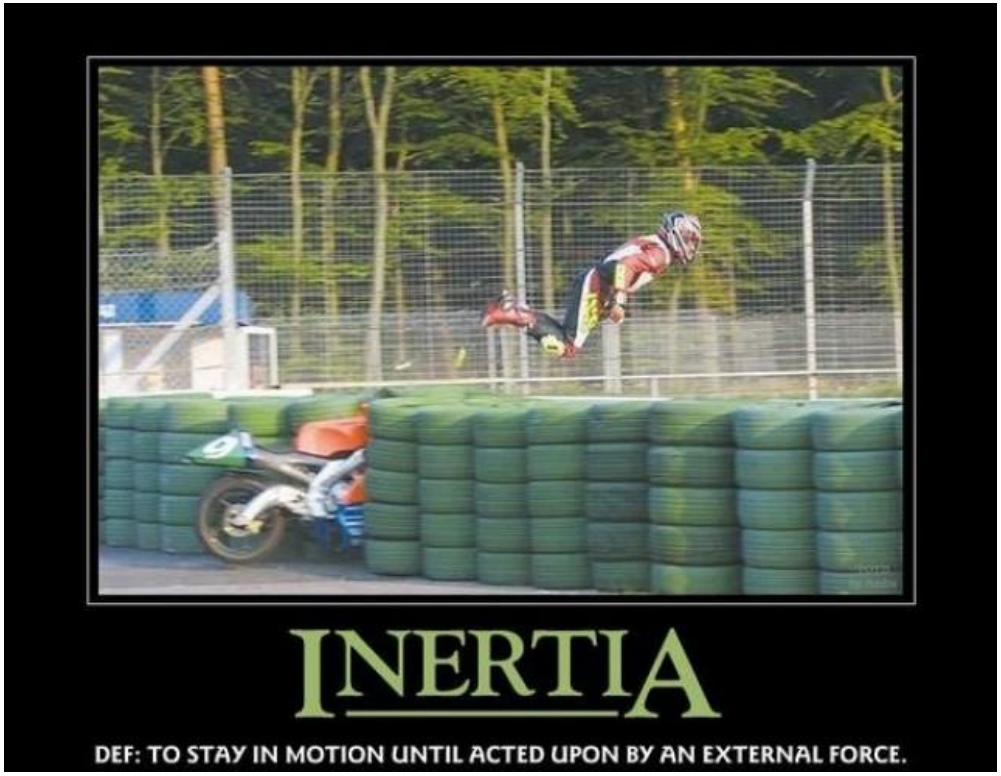


See how our concepts of motion have change in time.
And get an idea why incorrect theories can persist for so long!

We look at constant velocity

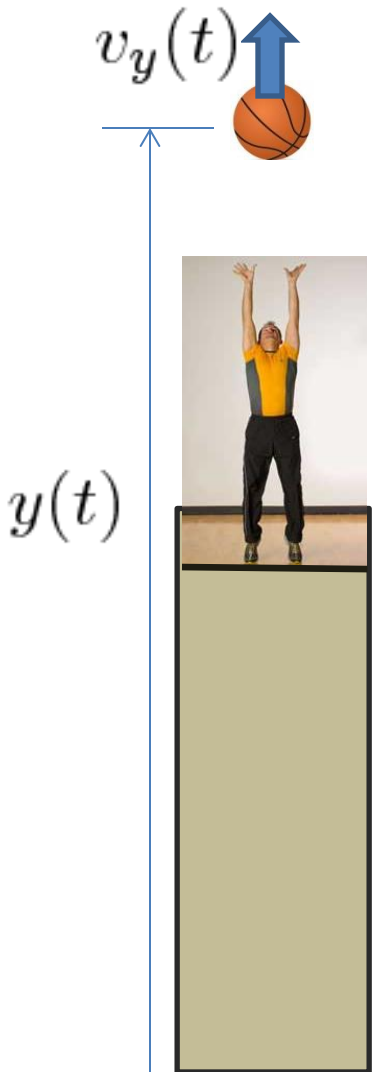
We look at constant acceleration

We look at Newton's second law



$$F=ma$$

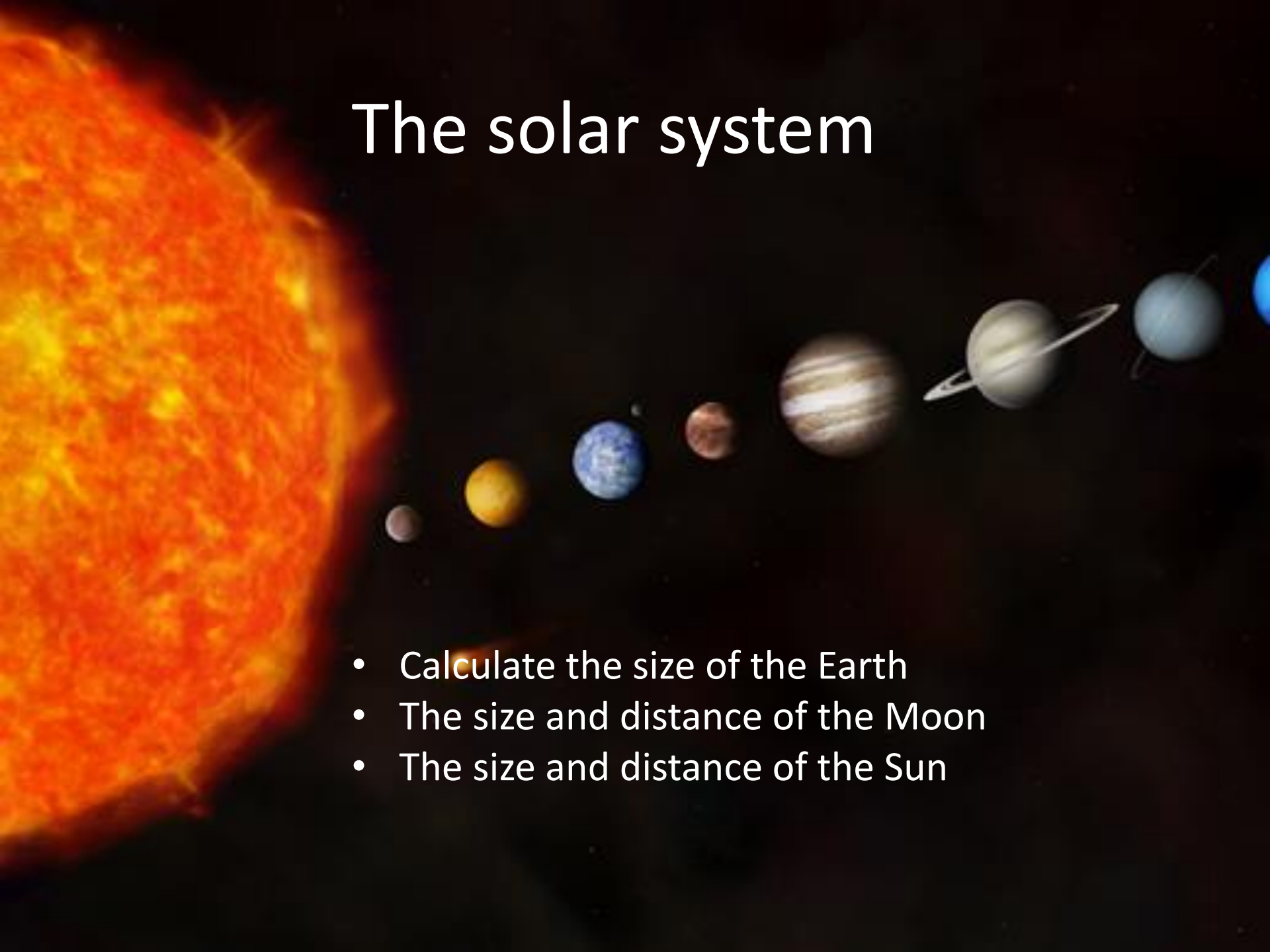
We look at gravity and how objects fall in a gravitational acceleration



We look at weight

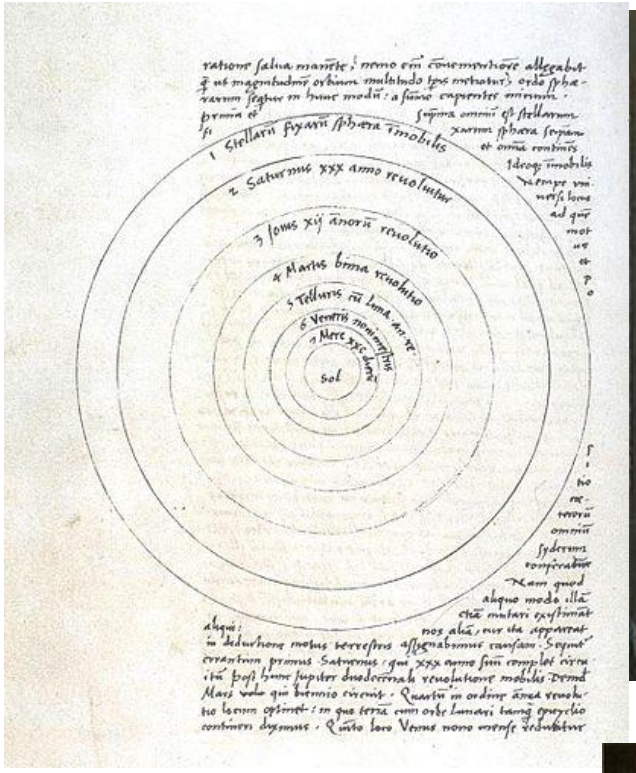
And weightlessness….

The solar system



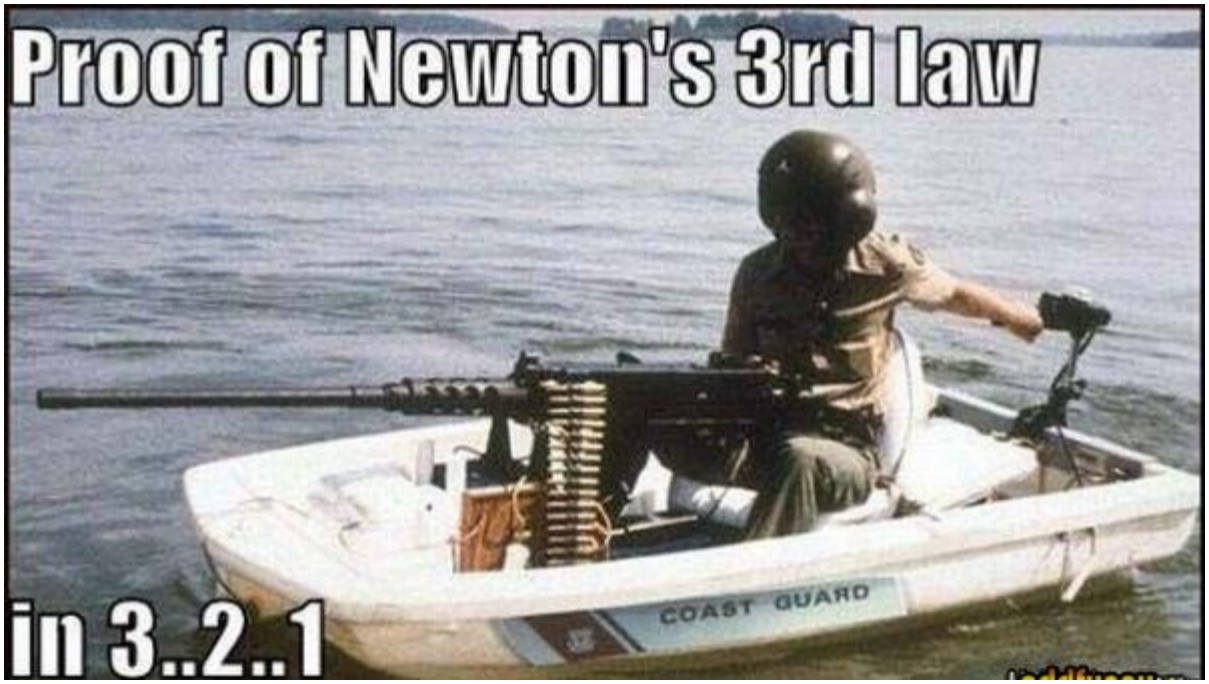
- Calculate the size of the Earth
- The size and distance of the Moon
- The size and distance of the Sun

We look at models of our Solar system



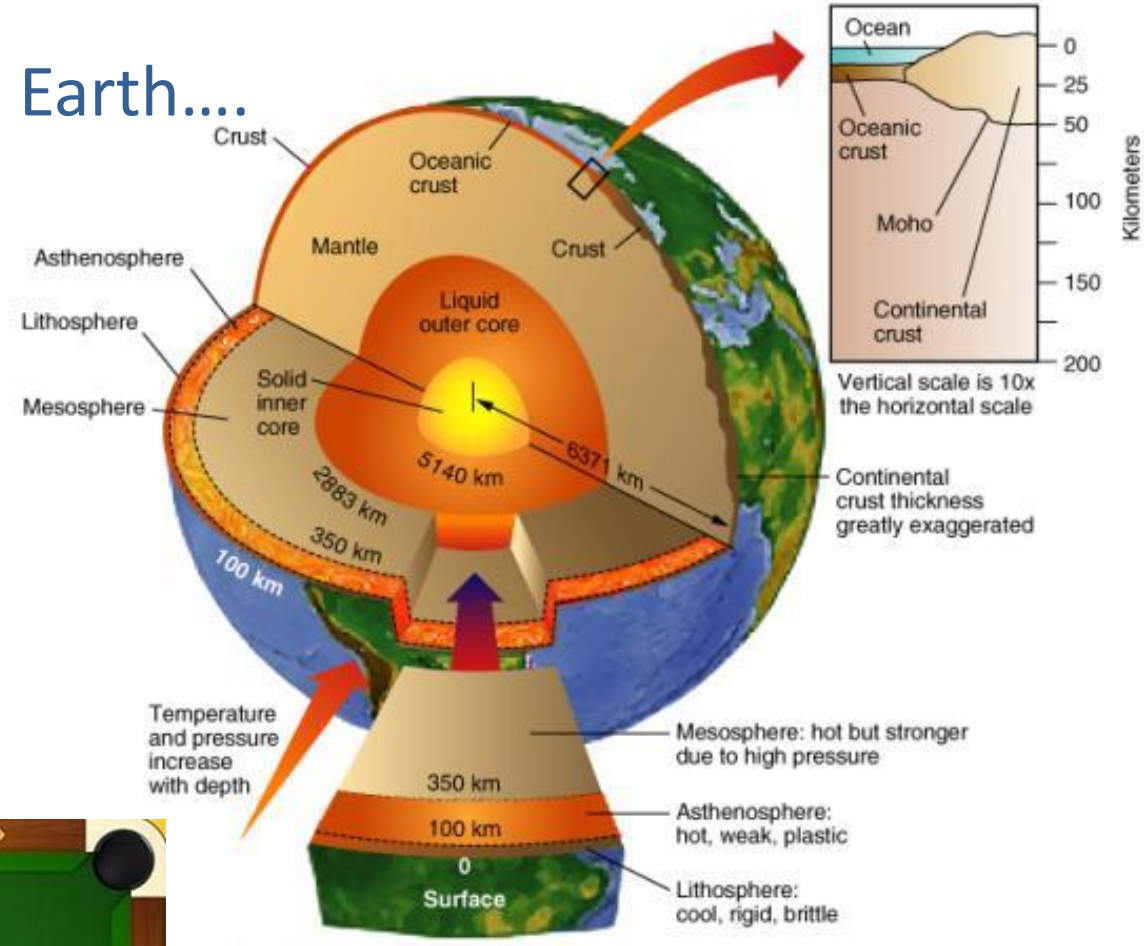
And study Kepler's laws

We look at Newton's third law.



Study the tides

Have a look inside the Earth….



Play some pool….

(okay, that sounds more fun than it is)

We look at the reason why certain physical quantities are conserved

An we end the classical part with pressure.

And after that…..
I don’t know yet.