PRESENTING

TECHNOLOGICAL GROWTH, PHYSICS ADVANCES AND MEDICINE

A PRESENTATION ON "LIGHT MEETS MATTER: ATOMS AND LASERS" BASED ON THE 2009 KITP TEACHERS' CONFERENCE

AS TOLD TO STUDENT "**NEWTON**" BY

DR. V

OVERVIEW

- Introduction
- Technological Progress
- Quantum mechanics
- Summary

INTRODUCTION

Most of what you will see today is from the presentations of the following:

- Martin Plenio (Imperial College, London)

- Peter Knight (Imperial College, London)

- Yaron Silberberg (Weizmann Inst., Israel)

- Paul Corkum (Nat'l Research Council of Canada)

INTRODUCTION

BUT WAIT,DR.V,

“THERE ARE NO SCIENTISTS THAT LOOK LIKE MY FRIENDS HERE OR LIVE WHERE I LIVE”

That is where YOU, NEWTON, and your frinds come in. You may be a presenter at a conference like this in the future.

TECHNOLOGICAL PROGRESS

In this section we will discuss the progress made in the following areas:

Space-time measurement

Computational power

Ability to distinguish small time intervals

Microscopes

TECHNOLOGICAL PROGRESS

Space-Time Measurement

BORING, BORING, DR.V!

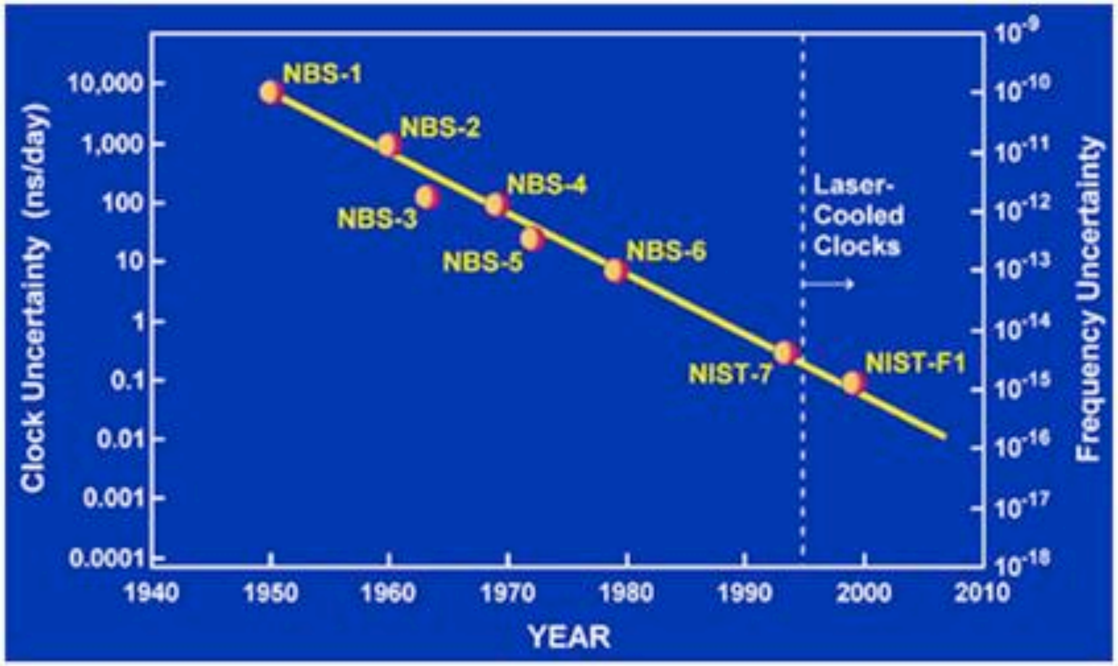
Well, Newton, you know those navigation devices you use in your car, we could not have had them 20 years ago.Let's see why?

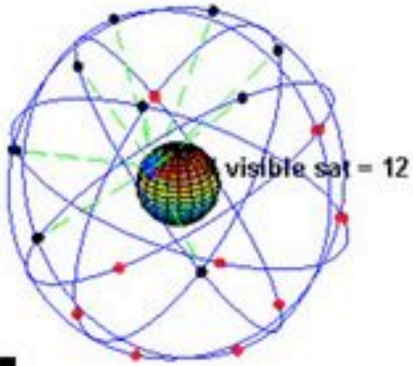
The next slide is from

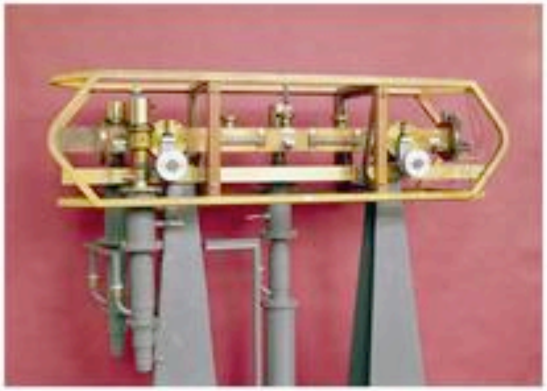
Martin Plenio's

Presentation.

Measurement of time gains in precision exponentially







Essen & Parry @ National Physical Laboratory 1955

TECHNOLOGICAL PROGRESS

Space-Time Measurement

SO, DR.V. HOW DO THE CLOCKS ENABLE US TO HAVE NAVIGATION DEVICES?

Atomic clocks must be very, very precise because satellites (multiple) must:

1. *Exchange signals with the navigation device.*
2. *Measure the time these signals take to travel from the device to the satellite(s)*
3. *From the different times (and distances) measured by multiple satellites, your position can be determined. (General relativity is also taken into account)*

TECHNOLOGICAL PROGRESS

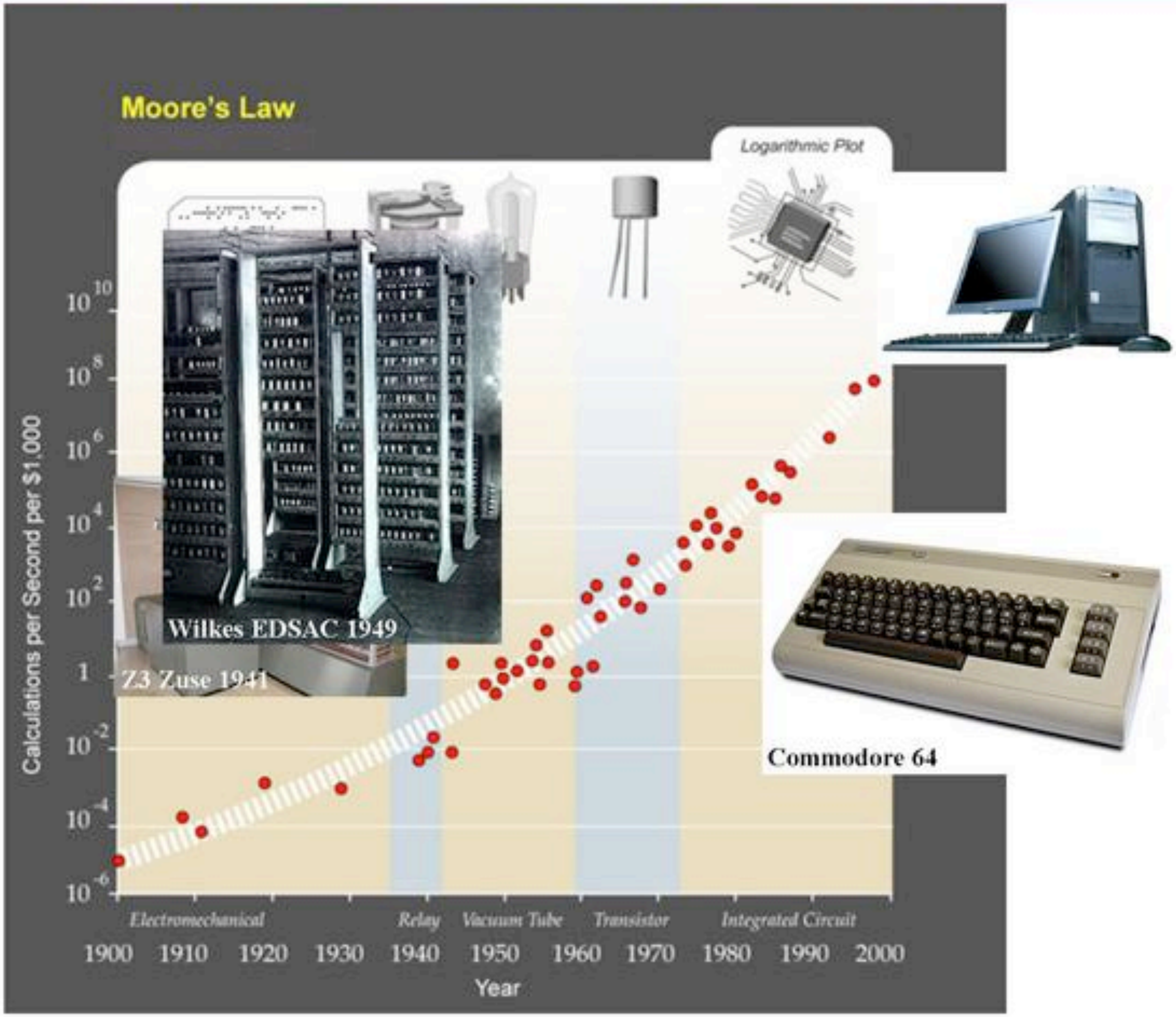
Computational Power

SO WHAT IS THIS?. *Well, Newton, we humans have always worked to develop tools to do some of our work for us. Some of the tools help us do mathematical and logical calculations.*

Let's look at another slide of Martin Plenio's

Computer grow faster exponentially

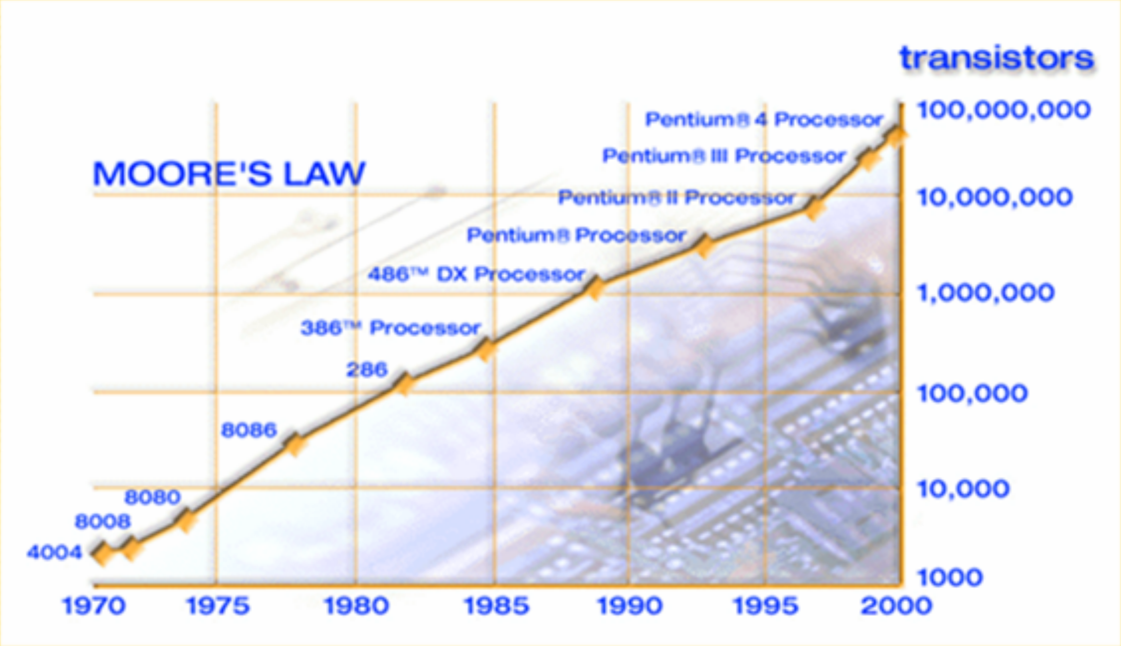
Kelvin's tide predictor 1872



TECHNOLOGICAL PROGRESS

Computational Power

HEY, DR. V, WHAT IS THAT THING CALLED "MOORE'S LAW" THAT IS ON THE LAST SLIDE?

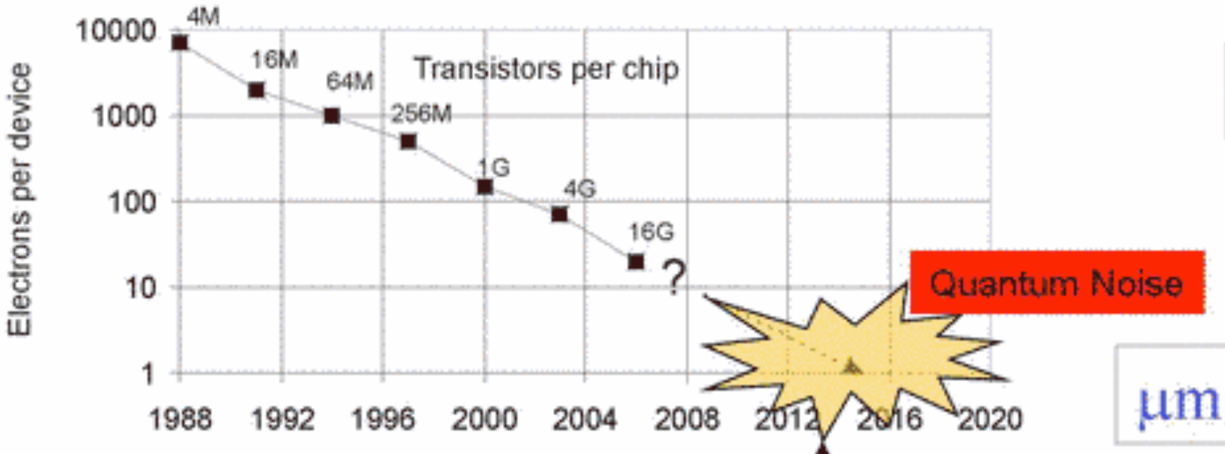


TECHNOLOGICAL PROGRESS
Computational Power

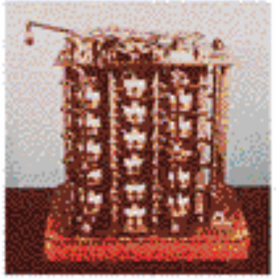
GEE, DR. V, HOW DO THEY GET ALL OF THOSE COMPONENTS IN THE COMPUTER?

Well, We will look at another slide from Martin Plenio's presentation

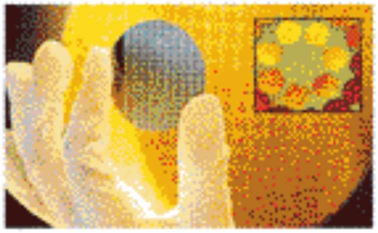
Components grow smaller exponentially



cm

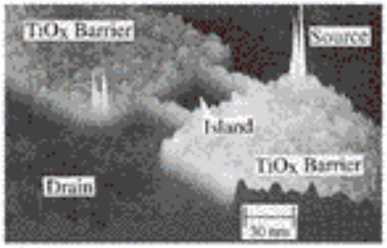


µm



Quantum technology

nm



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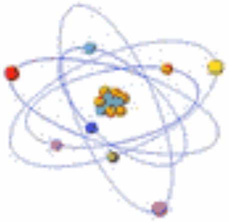


TECHNOLOGICAL PROGRESS
Computational Power

So we have seen that in order to progress to where we are today, we have had to change technologies. We have travelled from mechanical technologies to quantum mechanics. We will shortly learn about quantum mechanics.

TECHNOLOGICAL PROGRESS

Ability to “see” what is happening in shorter time intervals

WAIT! WAIT! WAIT! DR. V, WHAT ARE YOU TALKING ABOUT?

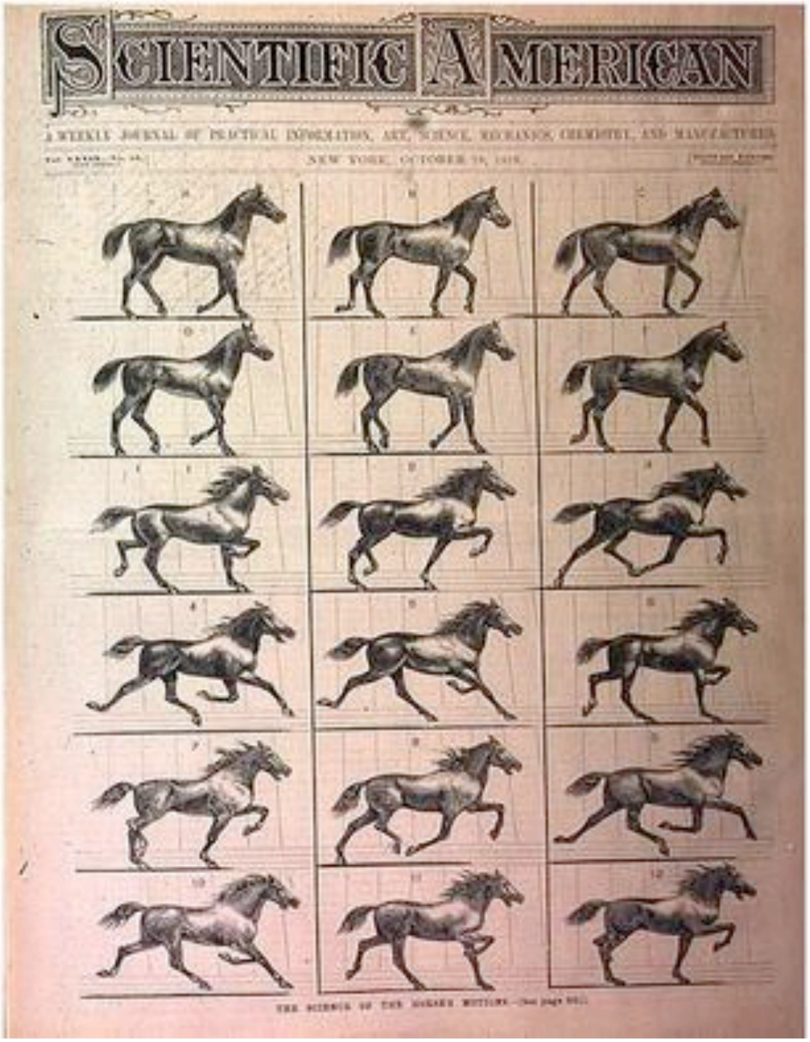
We will look at some slides from Paul Corkum's presentation to help you understand what we are talking about here.

“Milli”-Science

Eadward Muybridge

1878

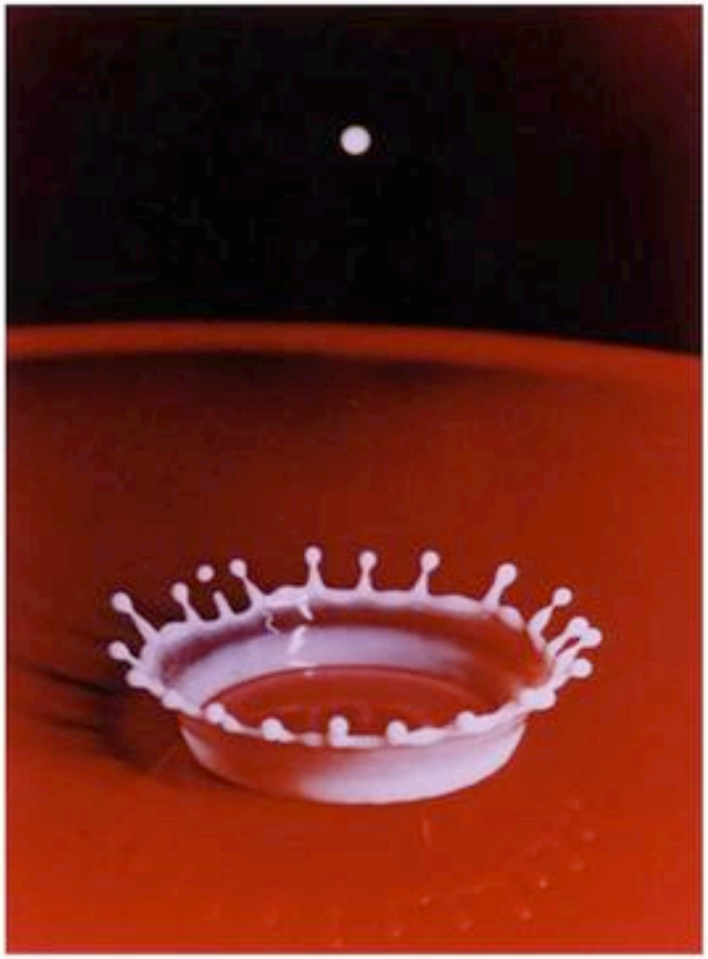
The first movies

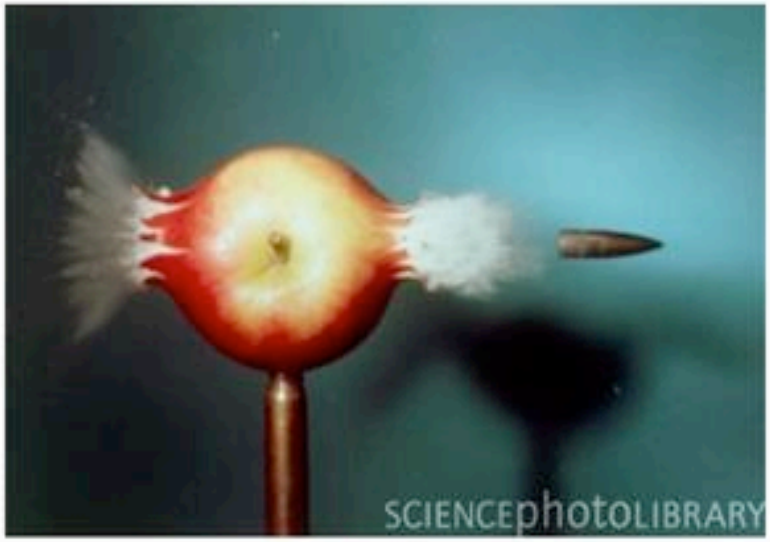


SCIENTIFIC AMERICAN

A WEEKLY JOURNAL OF PRACTICAL INFORMATION, ART, SCIENCE, MECHANICS, CHEMISTRY, AND MANUFACTURES.

“Micro”-science: Art and Science are one





Harold E. Edgerton

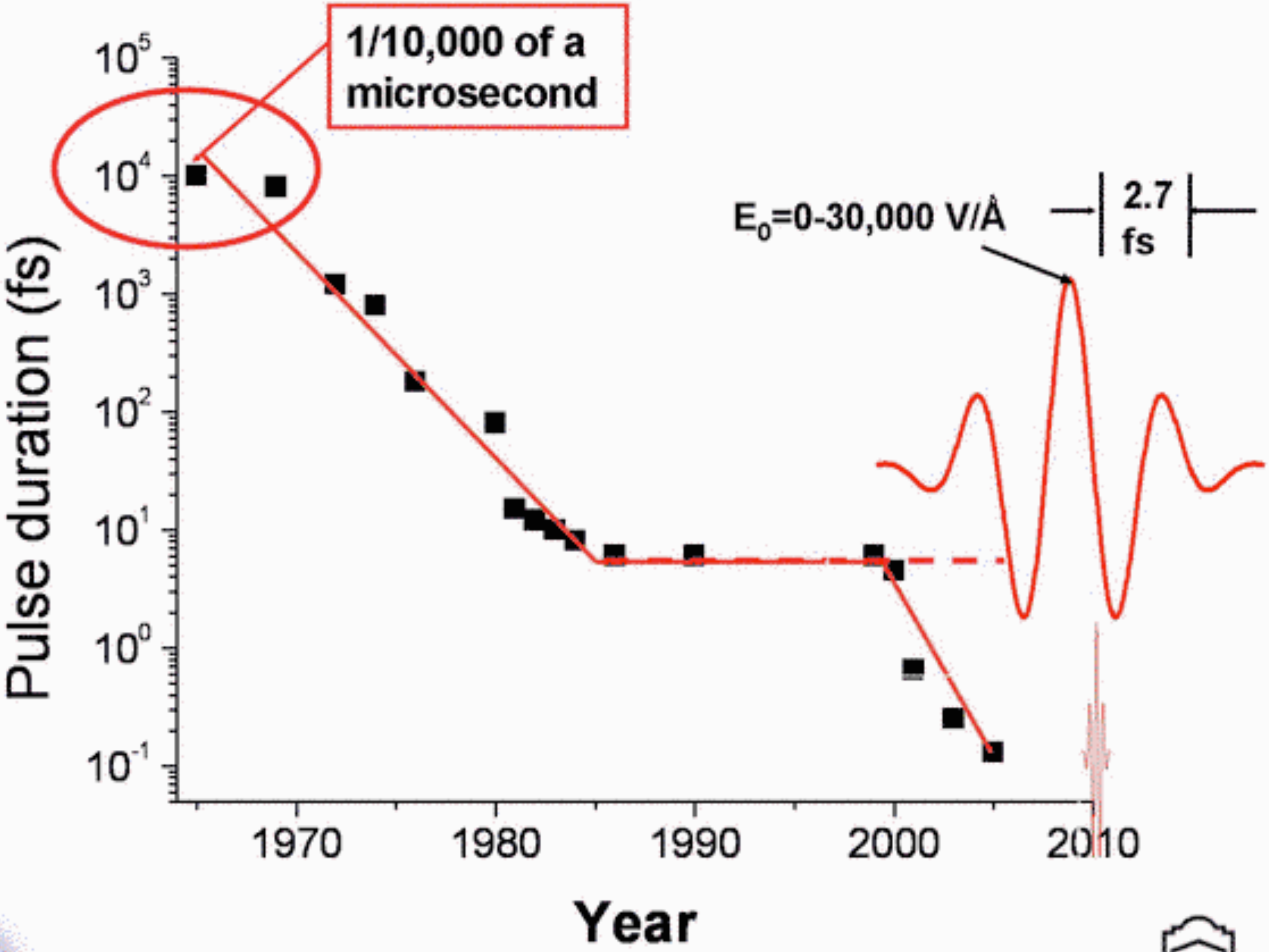
1938

TECHNOLOGICAL PROGRESS

Ability to “see” what is happening in shorter time intervals

Now we can look at some more of Paul Corkum’s slides to see what progress has been made in our ability to “see” what is happening in shorter time intervals.

A discontinuity in technology



NRC·CNRC

uOttawa

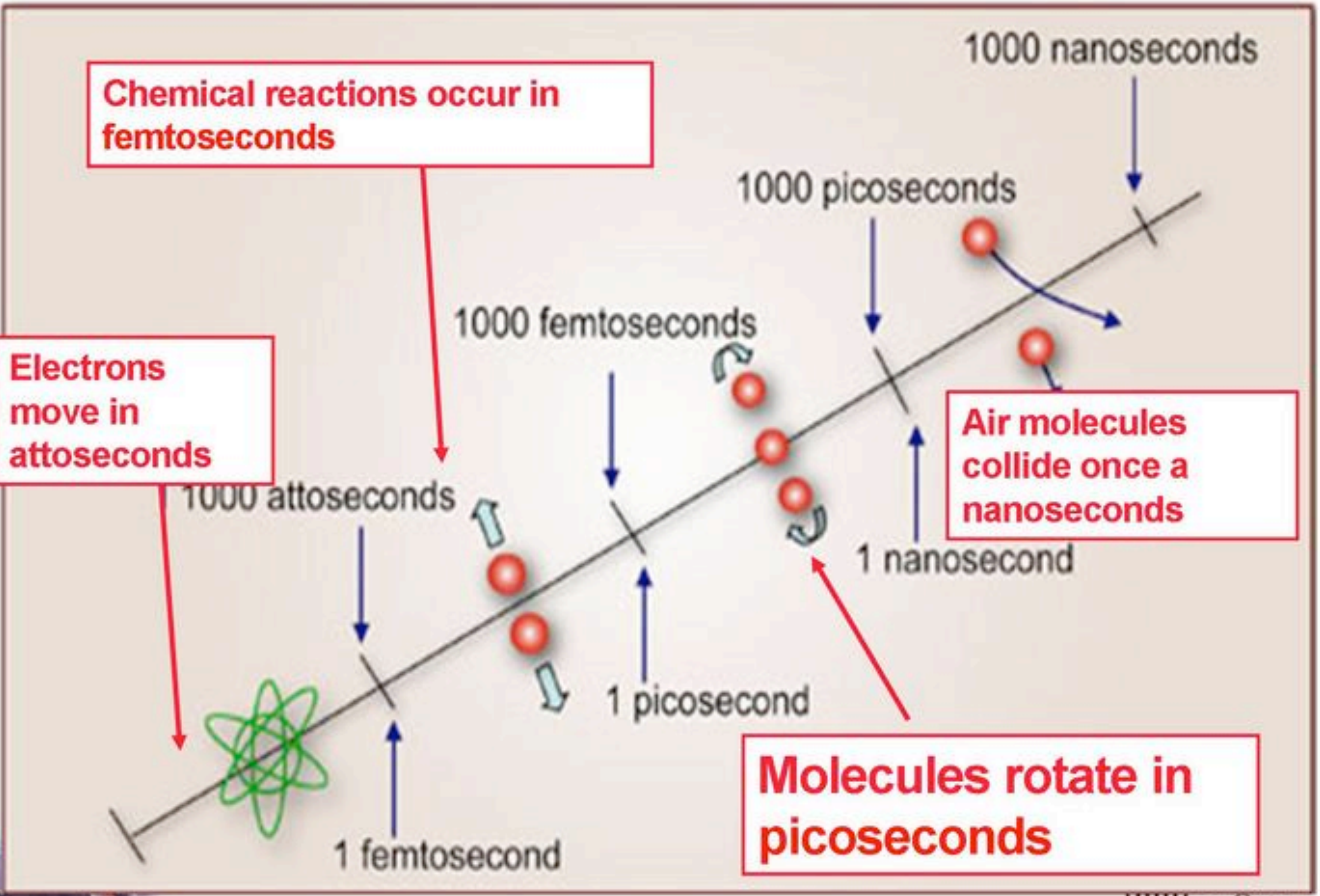
TECHNOLOGICAL PROGRESS

Ability to “see” what is happening in shorter time intervals

BUT DR.V, SO WHAT. WHAT DOES ALL OF THIS MEAN?

Again we will look at one of Paul Corkum’s slides to help us appreciate the accomplishment.

Faster than a microsceond -- the image is lost



Chemical reactions occur in femtoseconds

Electrons move in attoseconds

Air molecules collide once a nanoseconds

Molecules rotate in picoseconds

Everything that fast is too small to see with visible light.

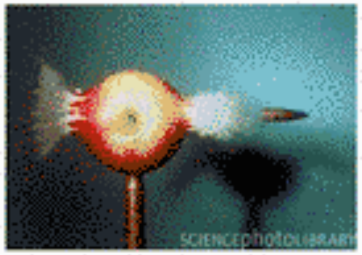
TECHNOLOGICAL PROGRESS

Ability to "see" what is happening in shorter time intervals

WHAT IS AN ATTOSECOND, DR.V.?

This question is answered in another of Paul Corkum's slides.

- Divide one second into 1,000,000,000 pieces



Nanosecond

- Take one nanosecond and divide it into 1,000,000,000 more pieces

That's an attosecond

TECHNOLOGICAL PROGRESS

Microscope Development

- 1021 - The properties of magnifying glass are first clearly described by the Arabic physicist, Ibn al-Haytham (Alhazen), in his *Book of Optics*.[1]
- 1100s - The properties of magnifying glass becomes known in Europe after Alhazen's *Book of Optics* is translated into Latin
- 1200s - Spectacles are developed in Italy
- 1590 - Dutch spectacle-makers Zacharias Janssen and his son Hans Janssen, invented a compound microscope.

TECHNOLOGICAL PROGRESS

Microscope Development

- 1609 - Galileo Galilei develops a compound microscope with a convex and a concave lens.
- 1625 - Giovanni Faber of Bamberg (1574 - 1629) of the Linceans coins the word *microscope* by analogy with *telescope*.
- 1665 - Robert Hooke publishes *Micrographia*, a collection of biological micrographs. He coins the word *cell* for the structures he discovers in cork bark.
- 1674 - Anton van Leeuwenhoek improves on a simple microscope for viewing biological specimens.

TECHNOLOGICAL PROGRESS

Microscope Development

- 1860s - Ernst Abbe discovers the Abbe sine condition, a breakthrough in microscope design, which until then was largely based on trial and error. The company of Carl Zeiss exploited this discovery and becomes the dominant microscope manufacturer of its era.
- 1931 - Ernst Ruska starts to build the first electron microscope. It is a Transmission electron microscope (TEM)
- 1936 - Erwin Wilhelm Müller invents the field emission microscope.
- 1951 - Erwin Wilhelm Müller invents the field ion microscope and is the first to see atoms.
- 1953 - Frits Zernike, professor of theoretical physics, receives the Nobel Prize in Physics for his invention of the phase contrast microscope.

TECHNOLOGICAL PROGRESS

Microscope Development

- 1967 - Erwin Wilhelm Müller adds time-of-flight spectroscopy to the field ion microscope, making the first atom probe and allowing the chemical identification of each individual atom.
- 1981 - Gerd Binnig and Heinrich Rohrer develop the scanning tunneling microscope (STM).
- 1986 - Gerd Binnig, Quate, and Gerber invent the Atomic force microscope (AFM)
- 1988 - Alfred Cerezo, Terence Godfrey, and George D. W. Smith applied a position-sensitive detector to the atom probe, making it able to resolve atoms in 3-dimensions.
- 1988 - Kingo Itaya invents the Electrochemical scanning tunneling microscope
- 1991 - Kelvin probe force microscope invented.

TECHNOLOGICAL PROGRESS

Microscope Development

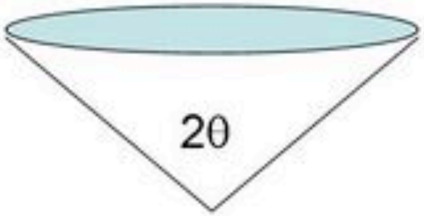
Let's look at some specific examples presented by Yaron Silberberg.

Carl Zeiss and Ernst Abbe – the first high-tech company?

Carl Zeiss (1816–1888)

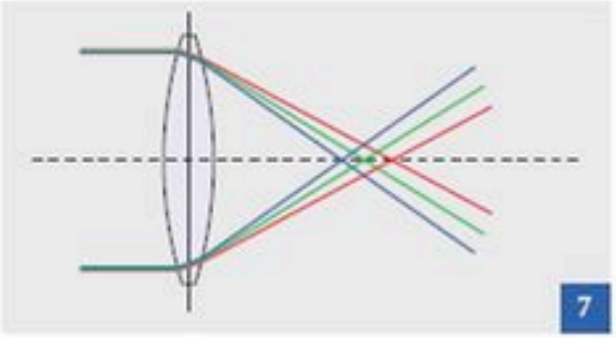
Ernst Abbe (1840–1905)

CARL ZEISS
JENA



$$d = \frac{\lambda}{2n\sin(\theta)}$$

Reaching the diffraction limit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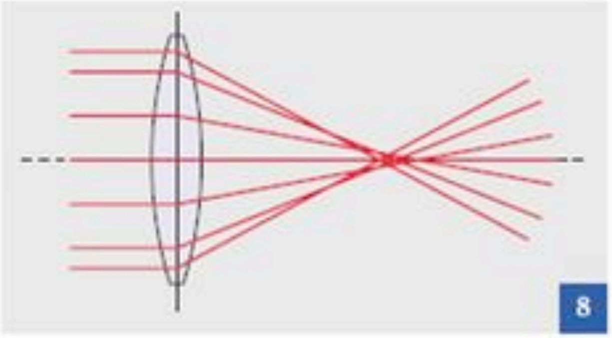
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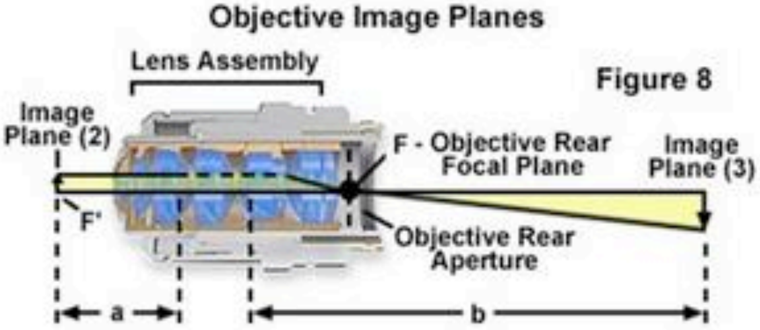


Figure 1

Zeiss and Schott

Otto Schott (1851-1935)

SCHOTT & GEN. JENA

Microscopy development brought the need for advanced optical glasses

1

2

3

QUANTUM MECHANICS
matter: wave or particle?

<u>Experimental demonstration of wavelike property of electrons</u>

Davisson-Germer Experiment

1925-American physicists C.H. Davisson and L.H. Germer accidentally observed electron interference.

1927-published findings

1937-shared Nobel Prize with G.L.Thompson

http://video.google.com/videoplay?docid=-4237751840526284618

QUANTUM MECHANICS matter: wavelength-momentum relationship

“The diffraction of electrons indicates that we need to develop a system for describing the wave behavior of small objects. From observation we learn that the wavelength of an object is related to its momentum. The relationship is given by the DeBroglie equation:

$$\lambda = \frac{h}{mV} = \frac{h}{m\sqrt{\frac{2eV}{m}}} = \frac{h}{\sqrt{2meV}}$$

where h is Planck's Constant (6.63E-34 J s = 4.14E-15 eV s), named for Max Planck.”

QUANTUM MECHANICS
Schrodinger’s Equation

When considering objects as small as electrons, the equivalent to Newton's Laws is an equation which was originally written down by Erwin Schrödinger. This equation cannot be derived from any fundamental law but is based on several well established principles of physics.

QUANTUM MECHANICS
Schrodinger’s Equation

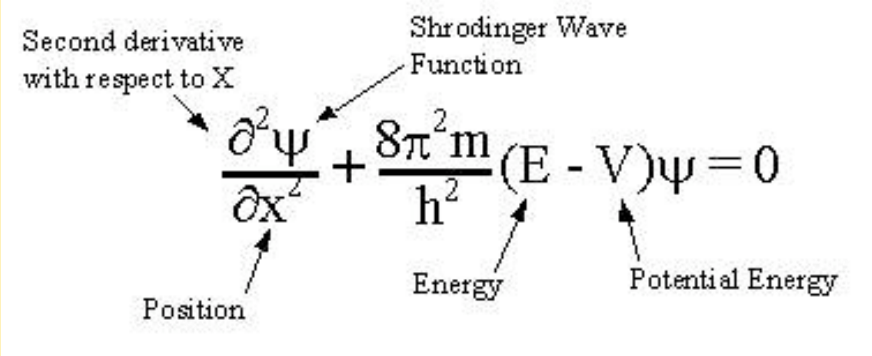
The basic ingredients in Schrödinger's Equation are:

1. The equation which relates the wavelength of an object to its momentum.
2. Conservation of energy,
3. Knowledge about how waves, such as water waves, behave, and
4. Accounting for forces which act on the object by using changes in potential energy.

QUANTUM MECHANICS
Schrodinger's Equation

Once the equation is set up for a particular situation, someone with an advanced math background or a computer can solve the equation. The result is a mathematical relation called a wave function.

Here is what the equation looks like:



$$\frac{\partial^2\psi}{\partial x^2} + \frac{8\pi^2 m}{h^2}(E - V)\psi = 0$$

QUANTUM MECHANICS

OH DR.V. MY HEAD IS SPINNING WITH THE NUMBERS. BUT I DID LIKE THE VIDEO.

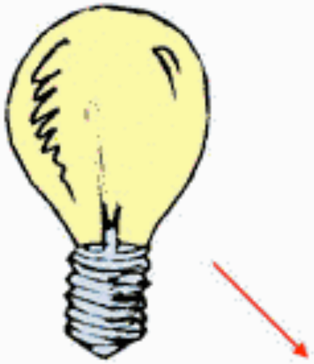
Alright Newton. We'll go on with why quantum mechanics is important. For these discussions, we will be referring to Martin Plenio's slides again.

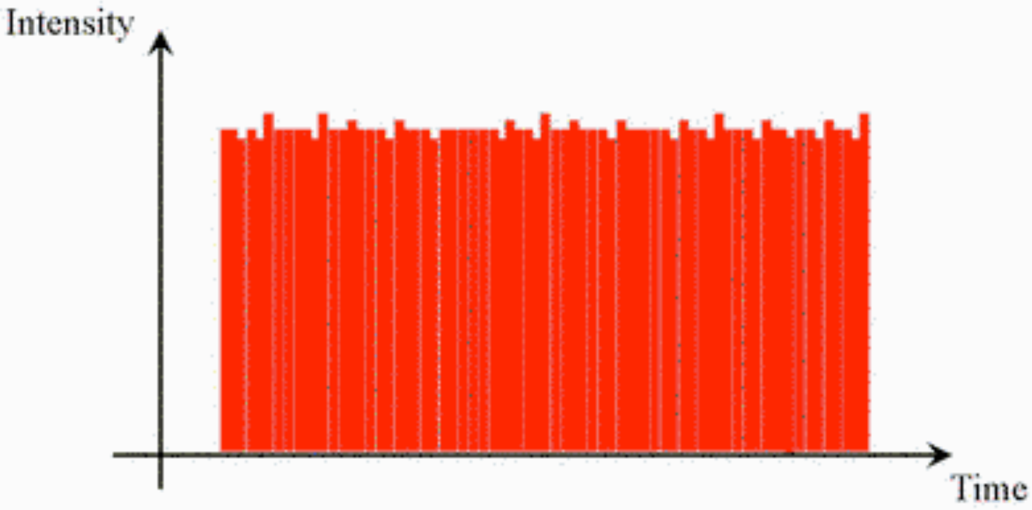
QUANTUM MECHANICS
Why is it important?

First we will examine what happens to the intensity graph of a lightbulb as the intensity lessens

Quantum vs Classical: Some key differences

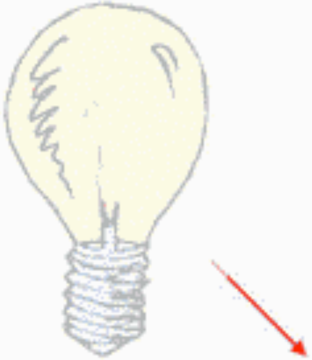
High intensity:

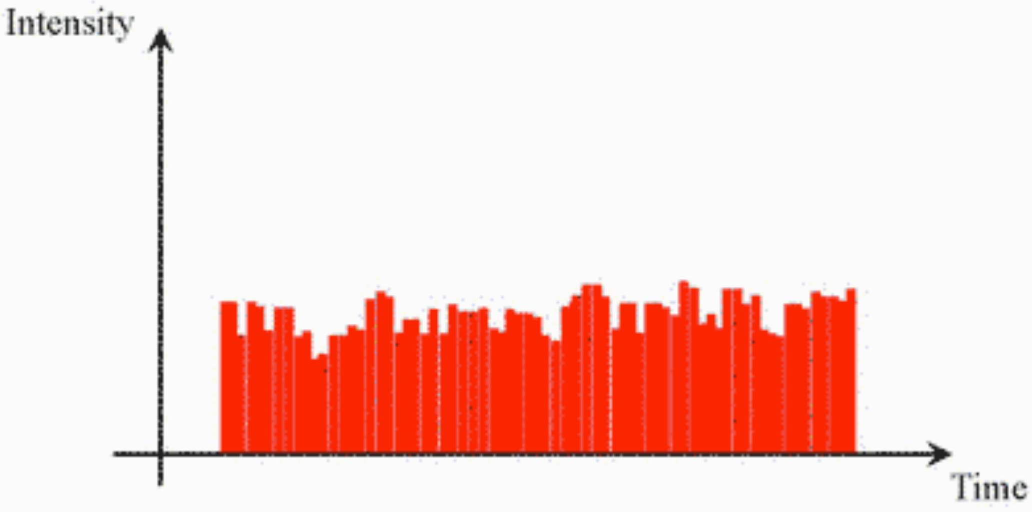


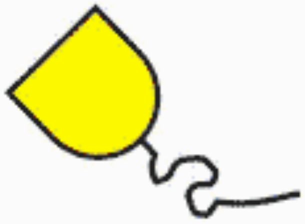


Quantum vs Classical: Some key differences

High intensity:

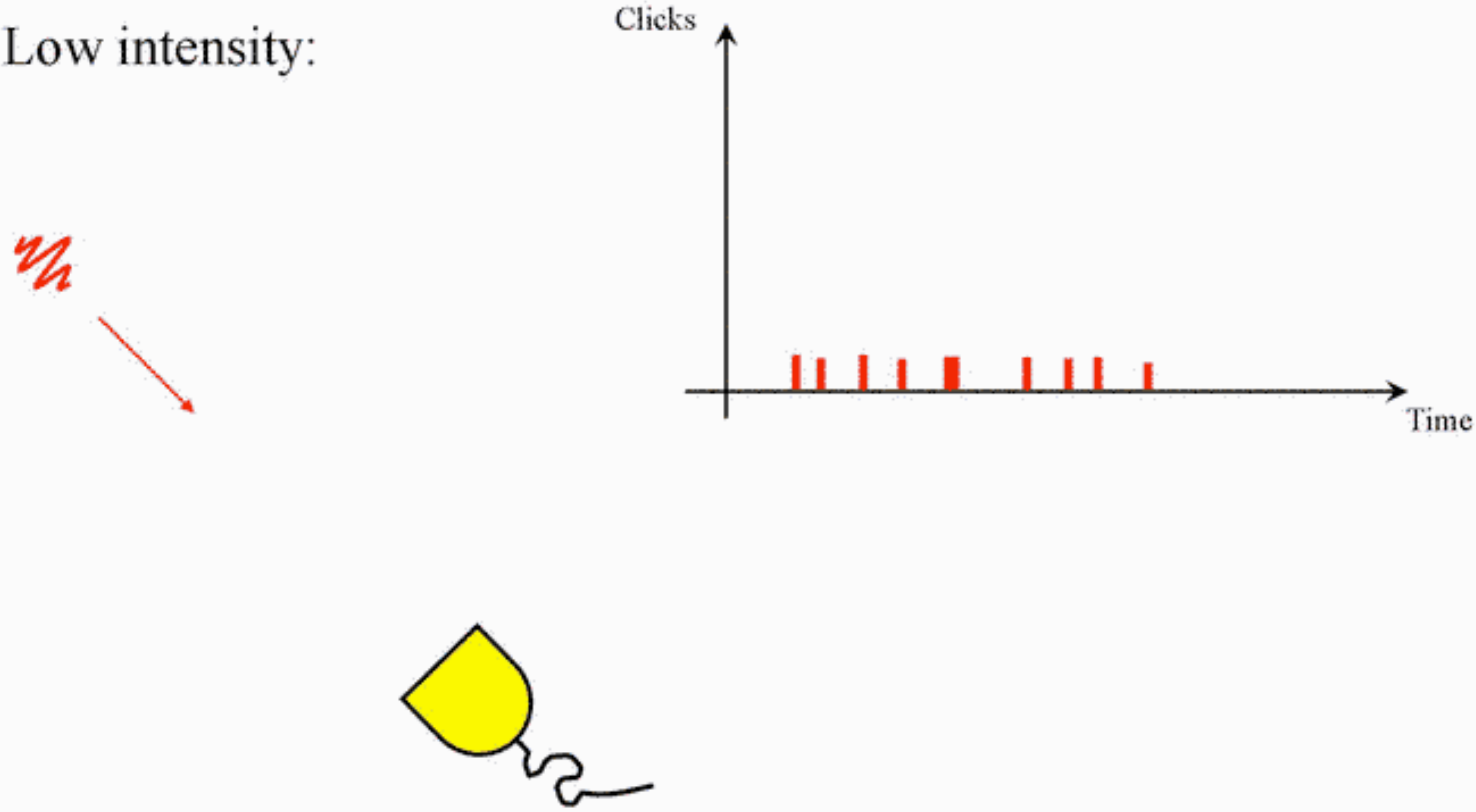






Quantum vs Classical: Some key differences

Low intensity:



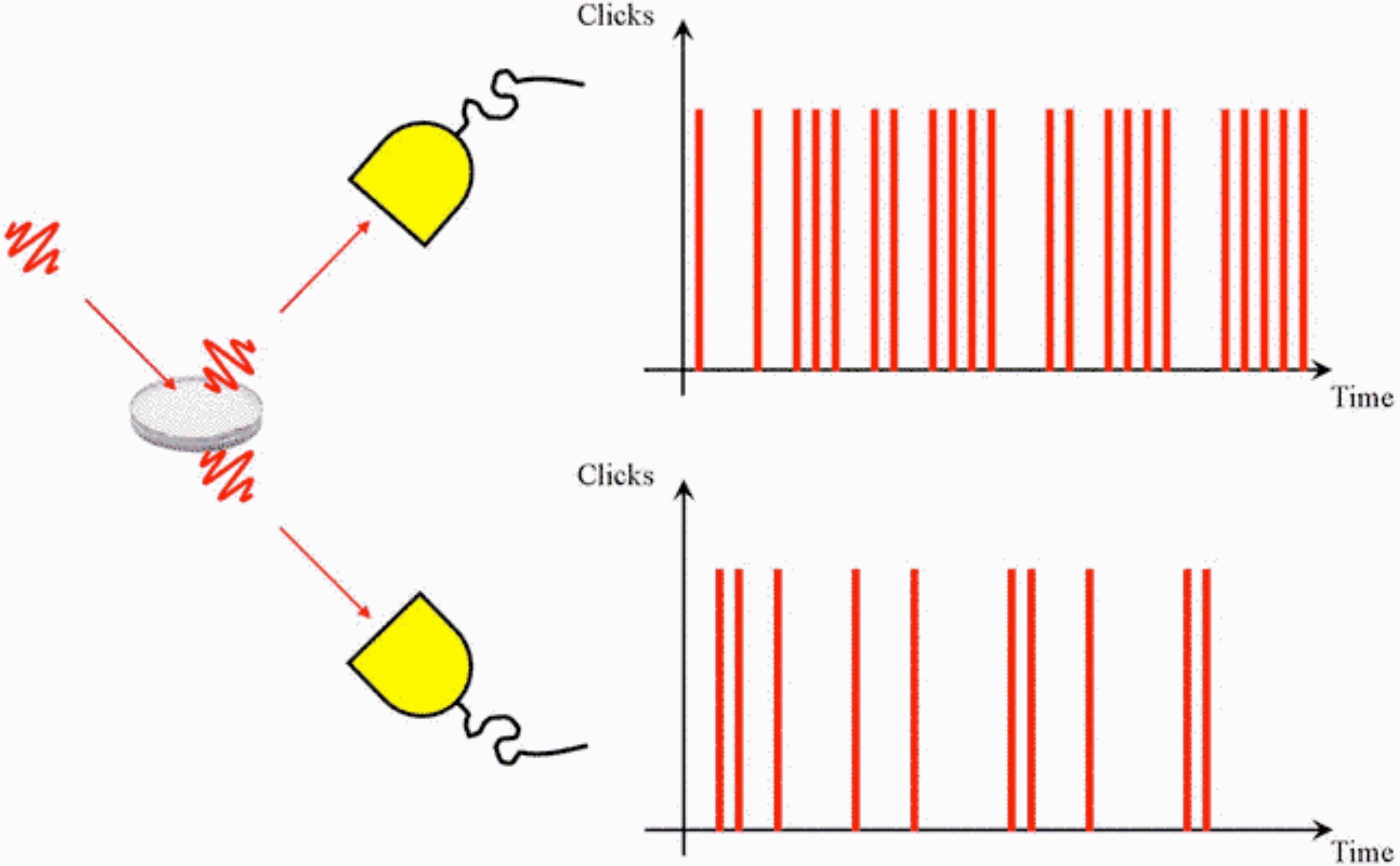
Light comes in little portions → Photons

QUANTUM MECHANICS
Why is it important?

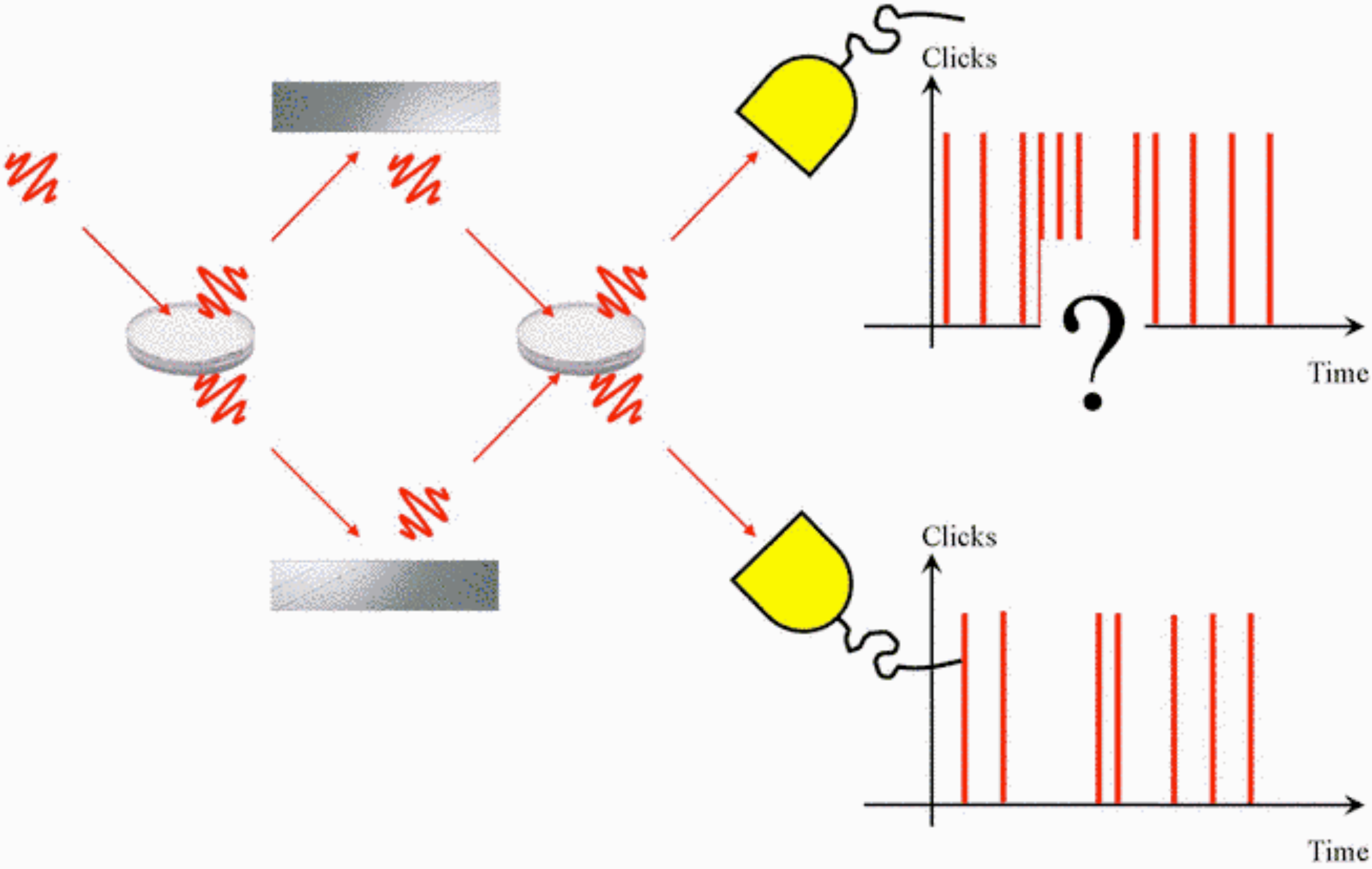
OK. DR.V. THAT IS VERY INTERESTING. AND I UNDERSTOOD IT.

Great! Now we are going to use Martin Plenio's slides to illustrate something very interesting. Pay careful atterntion.

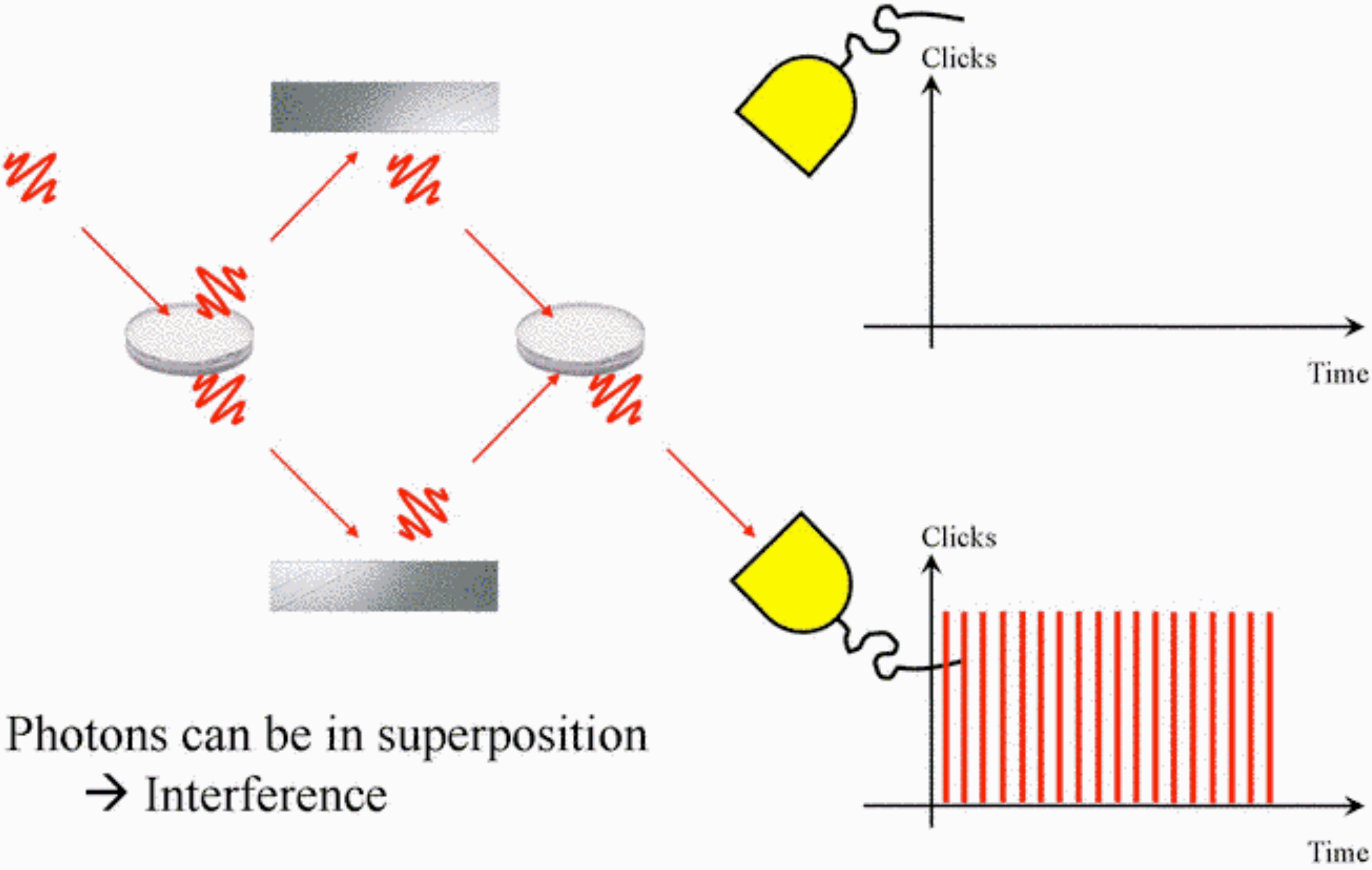
Quantum vs Classical: Some key differences



Quantum vs Classical: Some key differences

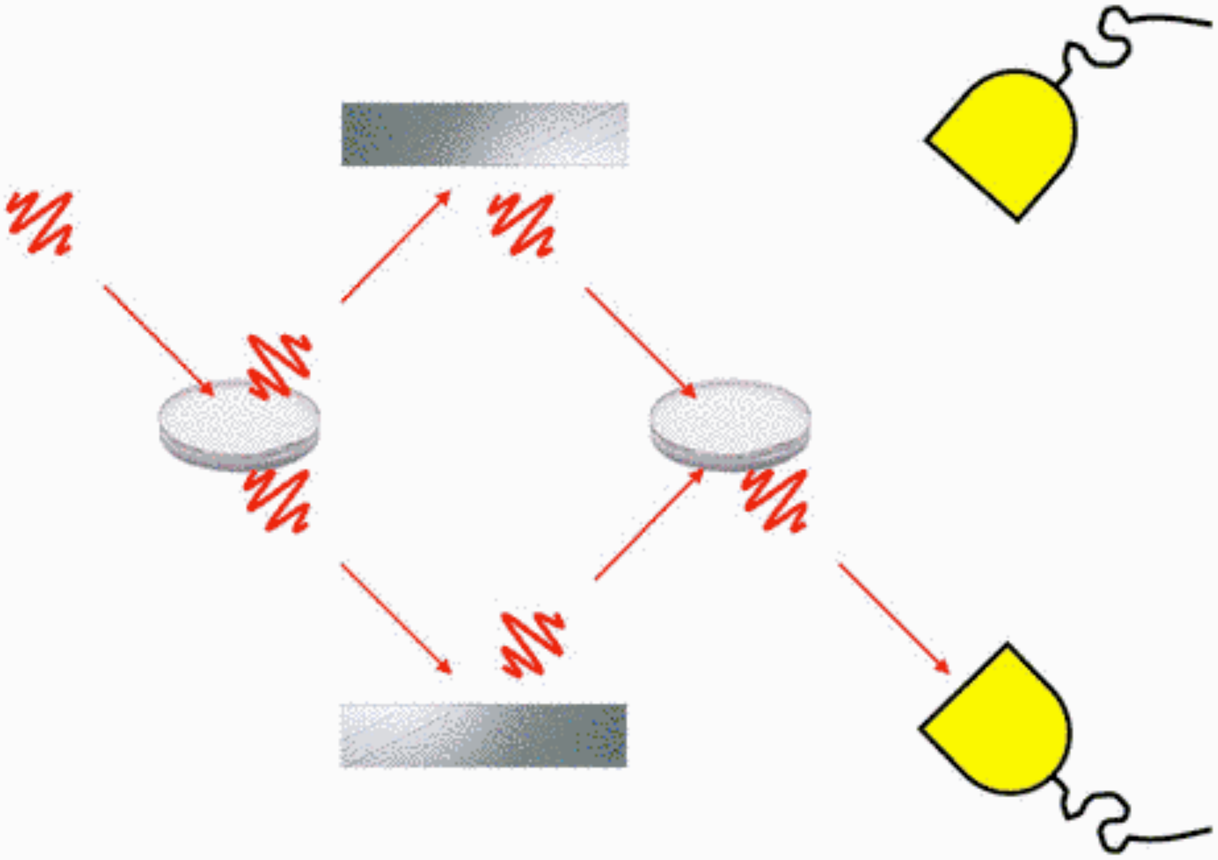


Quantum vs Classical: Some key differences

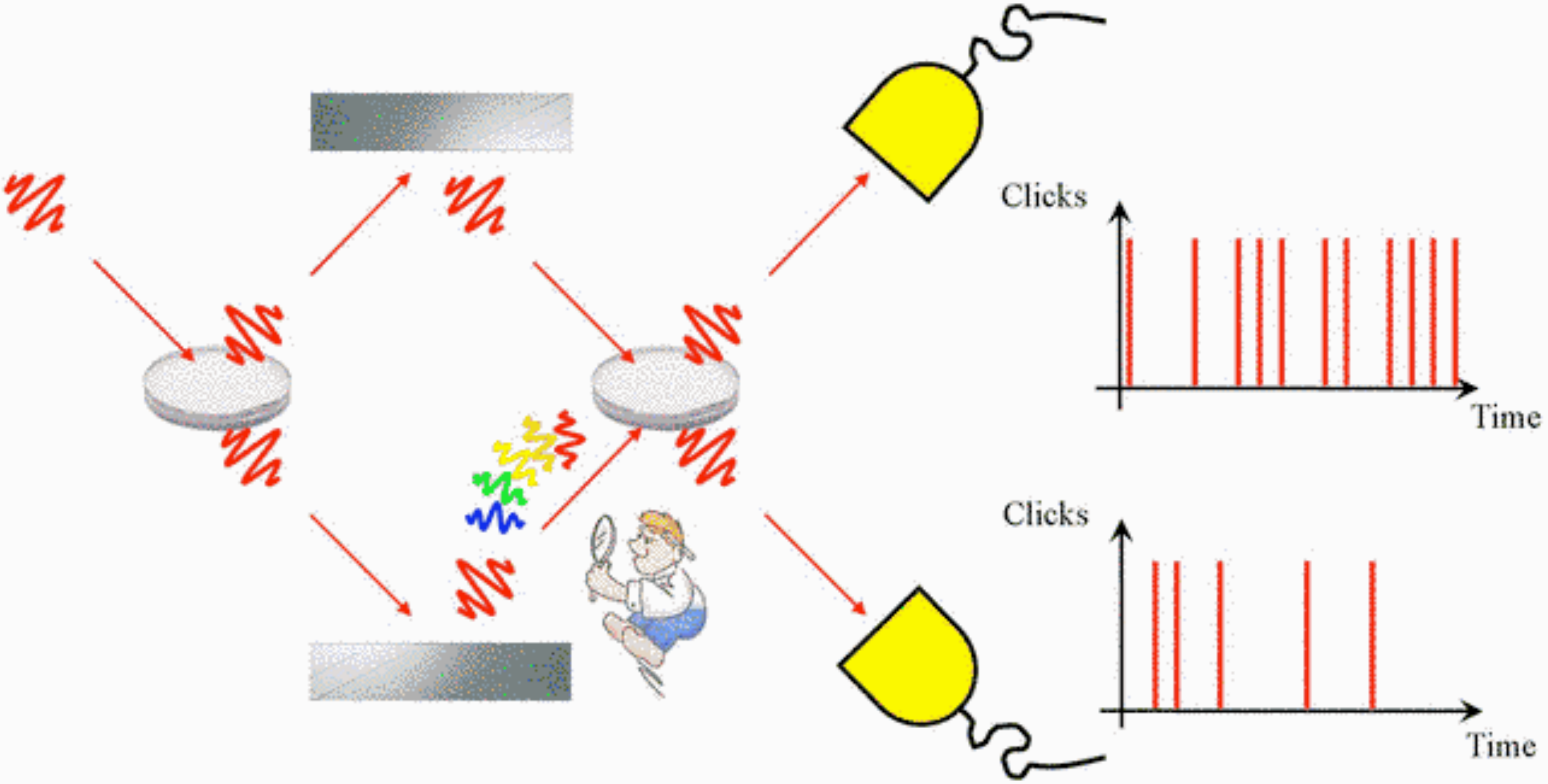


Photons can be in superposition
→ Interference

Quantum vs Classical: Some key differences



Quantum vs Classical: Some key differences



QUANTUM MECHANICS
Why is it important?

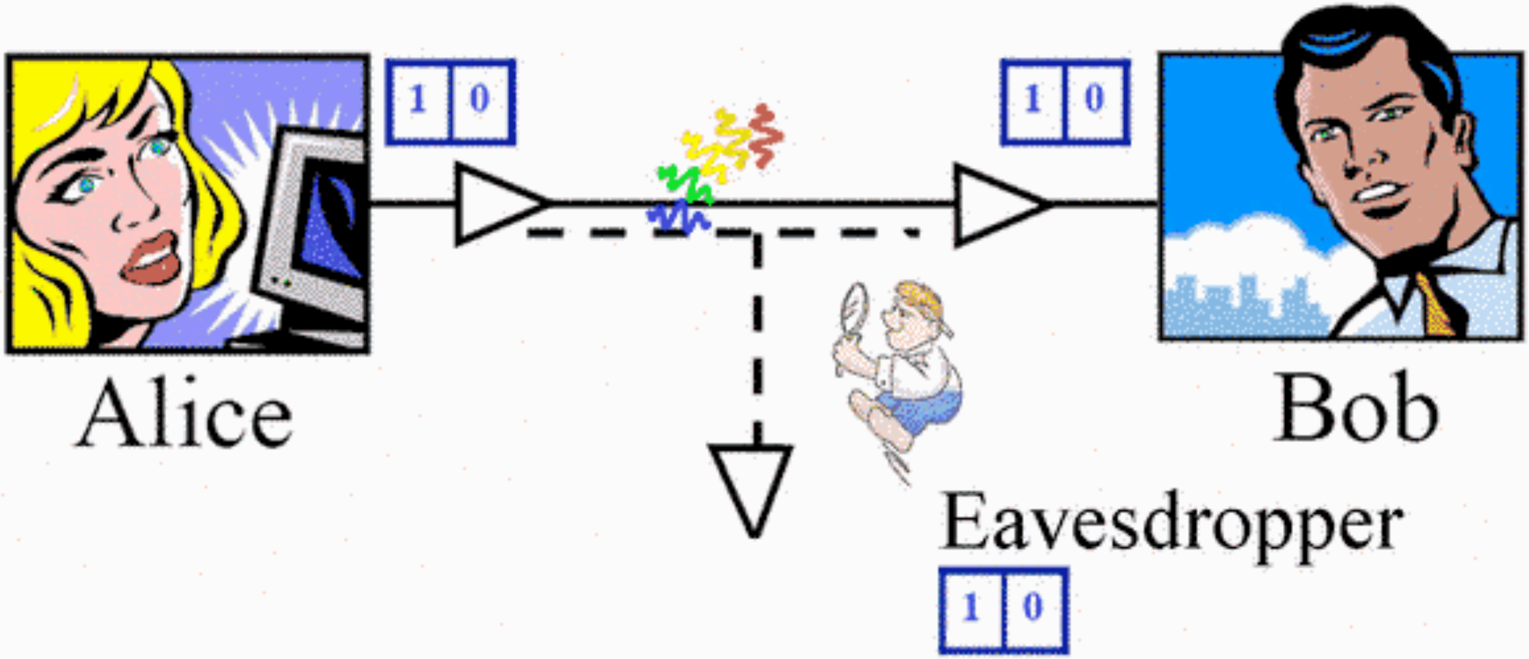
WOW DR.V. THAT IS WEIRD. BUT HOW CAN WE USE IT?

To summarize what we have learned so far:

- *When a quantum system is in free space, it behaves like a wave.*
- *When a quantum system is being "watched," it behaves like a particle*
- *We can always observe when a quantum system is being "Watched."*

Now lets look at some more of Martin Plenio's slides and see what we can do with this knowledge.

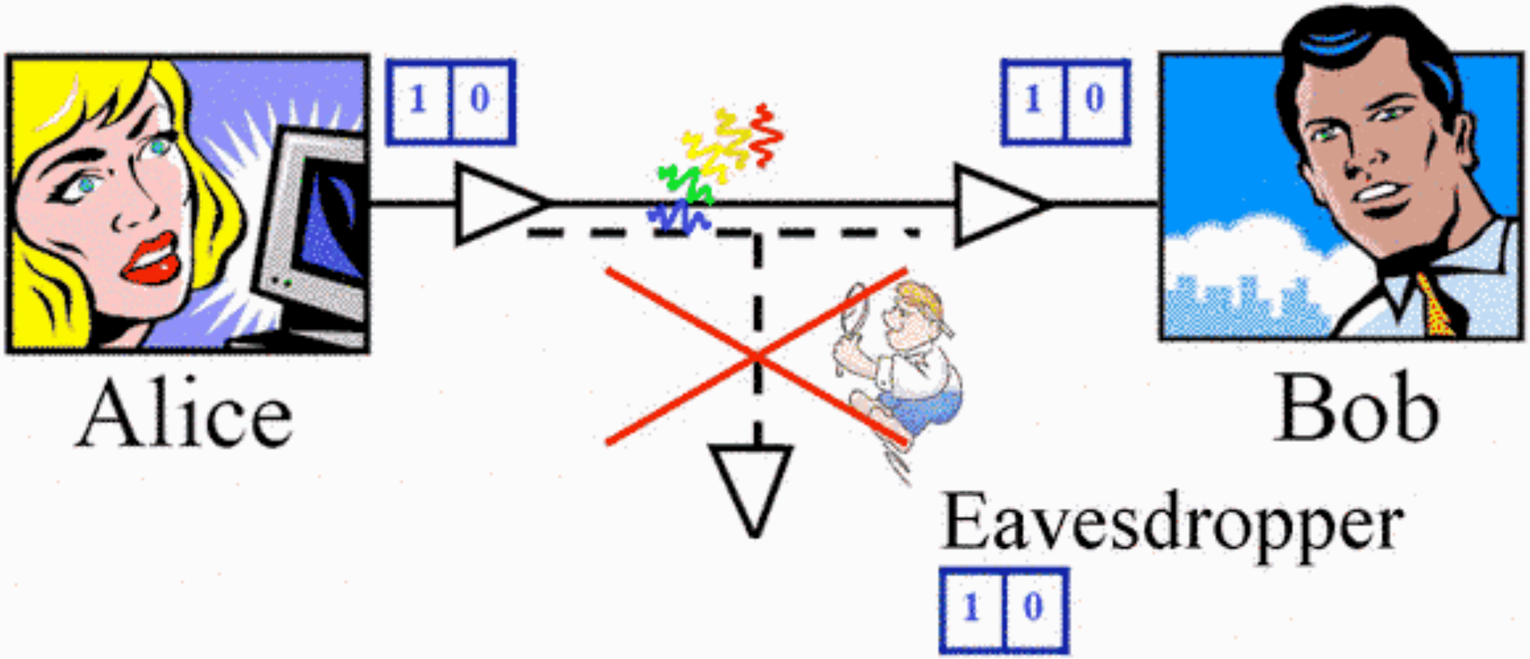
Secret Communication



Eve may measure classical signal without perturbation and hence without detection.

We do not know how much Eve has learnt about the key!

Secret Communication



Quantum World:

Eve's measurement of quantum signal causes perturbation and can be detected.

⇨

Noise level provides bounds on information leaked to Eve !

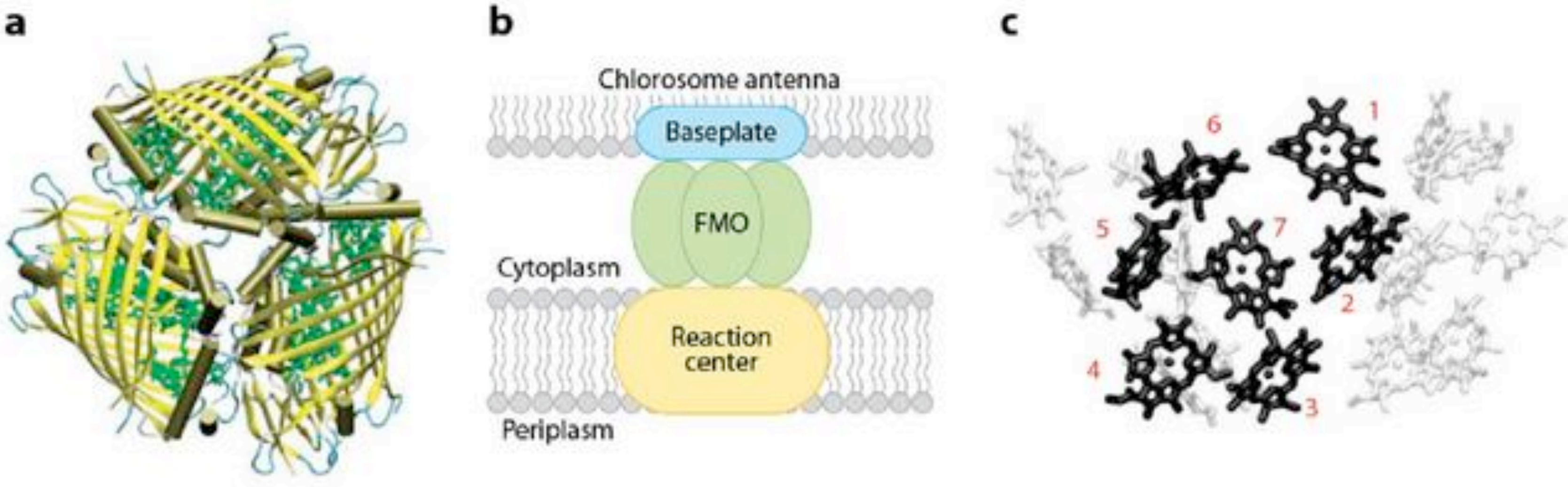
QUANTUM MECHANICS
Why is it important?

One more example of how "noise" benefits nature. The process of photosynthesis has been studied in certain bacteria that live in the bottom of the ocean, near sulfur springs. These bacteria undergo photosynthesis, but because of the very minimum light, must be very efficient.

Let's look at Martin Plenio's slides to tell the rest of the story.

Photosynthesis

Green sulphur Bacteria



SUMMARY
Medical implications

1. Microscope improvements lead to improved research and diagnosis.

3. Improving lasers so that they can reach the attosecond range can affect diagnosis and treatment of many diseases. Surgery could be improved, also.

5. Security is an important part of medical record keeping.

7. Can new technology,, involving noise addition, produce medical advancements?

8. Newton, this is an exciting time to be a student!

SUMMARY
The Joy of Being a Scientist

Paul Corkum had some slides at the end of his presentation that I would like you, Newton, and the rest of the students to see.

Atto-researchers

Canada

China

Cuba

England

France

Germany

Iran

Israel

Japan

Russia

Switzerland

NRC · CNRC

uOttawa

The Life of a Scientist