The Small and the Large in Physics

Brian G Wybourne

Instytut Fizyki,

Uniwersytet Mikołaja Kopernika - Poland

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So, naturalists observe, a flea
Has smaller fleas that on him prey;
And these have smaller still to bite 'em;
And so proceed ad infinitum.
Poetry, a Rhapsody. Jonathan Swift (1726)

Outline

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- 3. Lenses, Mirrors and Telescopes
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Lenses, Magnifiers and Microscopes

- 1.~**200 BC: Claudius Ptolemy** A stick appears bent in water. Measures AND calculates the refractive index of water.
- 2.~**100 AD: Seneca** *Letters, however small and indistinct, are seen enlarged and more clearly through a globe of glass filled with water*
- 3. **1267AD: Bacon** *Great things can be performed by refracted vision. If the letters of a book, or any minute object, be viewed through a lesser segment of a sphere of glass or crystal, whose plane is laid upon them, they will appear far better and larger.*

Lenses, Magnifiers and Microscopes

- Compound microscopes - More than one lense ~1595. Zacharias Jansen (?) Middelburg, Holland.
- Spherical and chromatic aberrations
- Resolving power is proportional to the wavelength.
- For higher resolution use shorter wavelengths - but ...
- Limits of light microscopes.
- Need for new physics and technology.

Lenses, Mirrors and Telescopes

- October 1608 Hans Lipperhey, Middelburg, Holland granted patent on a device for "seeing faraway things as though nearby".
- 9pm 26 July 1609 Thomas Harriot observes the moon and makes lunar sketches.
- October/November 1609 Galileo observes the moon and also discovers four satellites of Jupiter.
- December 1610 Thomas Harriot observes sunspots with his telescope. Notes that the sun rotates.
- 1671 Newton introduces the reflecting telescope. Eliminates the chromatic aberrations of lenses but has spherical aberration.

Resolving power of a Telescope

- Resolving power of a telescope is proportional to the wavelength divided by the diameter of the optics.
- For high resolution use short wavelengths and large diameter optics.
- To get to higher resolution, as with microscopes, we need new physics and technology.
- Could the necessary new physics and technology have been predicted?

Quantum Physics and Relativity

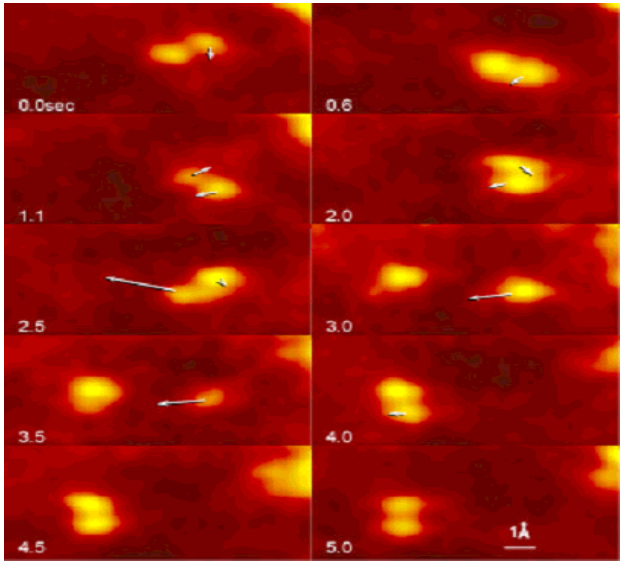
- To increase the resolution of microscopes we need to go to shorter wavelengths.
- 1923 de Broglie postulates that particles may exhibit wave-like properties

$$\lambda = \frac{h}{mv}$$

- 1927 Davisson, Germer and Thomson demonstrate diffraction and interference phenomena for electrons.
- Construction of electron microscopes becomes possible. Vision at a nanometre $10^{-9}m$ scale becomes possible.
- Need to construct electromagnetic lenses to control electron beams.

Quantum Physics and Relativity

- Relativistic kinematics essential.
- Compound electromagnetic lenses required to overcome aberrations.
- Particle accelerators also require compound electromagnetic lenses.
- High vacuum and superconductivity technology required.
- Atoms made visible.



1. August 8 2002 IBM, Nion Scientists Create World's Highest Resolution Electron Microscope.
2. Au Two-Atom Interaction. Single atoms of gold are easily observed on the surface of a carbon film. These move around, partly in response to interactions with other atoms, partly due to thermal fluctuations, and partly by interaction with the electron beam. When two of them approach, they feel an attractive force. As they approach closer, the attractive force turns into a repulsive force.
3. Electron beam diameter smaller than that of a hydrogen atom.

Some Units

- **Nanometre** $1nm = 10^{-9}m$
- **Ångström** $1\AA = 10^{-10}m$
- **fermi** $1fm = 10^{-15}m$
- **Planck length** $l_p = \left(\frac{\hbar G}{c^3}\right)^{\frac{3}{2}} \sim 10^{-35}m$
- **Light Year** $\sim 10^{16}m$

Some typical Sizes

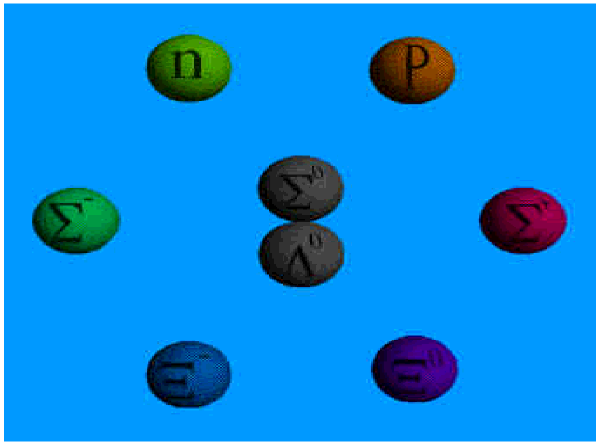
- **Atomic Radius H 2.08Å, Ne 0.51Å, Fr 2.7Å**
- **Nuclear Radius** $r = r_0 A^{\frac{1}{3}}$ $r_0 = 1.2fm$
- **A String** $\sim 10^{-35}m$
- **Earth Radius** $\sim 6.4 \times 10^6 m$
- **Sun Radius** $\sim 7 \times 10^8 m$
- **Observable Universe Radius** $\sim 10^{26}m$

The Range of Forces

- Strong Interaction Force:- Strength $= 1$ Range $10^{-15}m$
- Electromagnetic Forces:- Strength $= \frac{1}{137}$ Range infinite
- Weak Interaction Force:- Strength $= 10^{-5}$ Range $10^{-17}m$
- Gravitational Forces:- Strength $= 6 \times 10^{-39}$ Range infinite

A Matter of Some Gravity

- Almost nothing is known about gravity at distances shorter than 200microns
- This is 16 orders of magnitude worse than the other fundamental forces which have been tested down to $\sim 10^{-19m}$.
- Gravity is poorly tested on cosmological scales
- Extra Dimensions



The Baryon Octet

Nuclear matter involves predominantly protons and neutrons.

The proton and neutron, have radii of $\sim 10^{-15}m$.

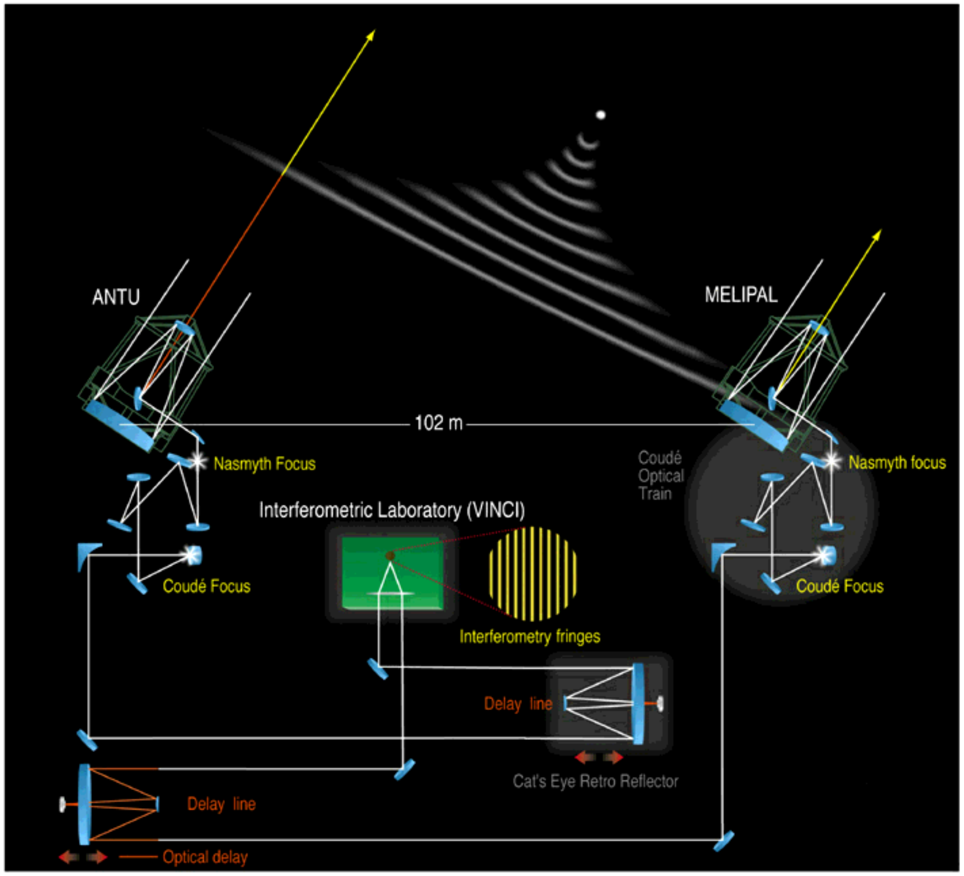
The protons and neutrons and bound by the strong force.

The protons and neutrons are composite particles - quarks.

The quarks are held together by the exchange of gluons.

Bigger and Better Telescopes

- Adaptive Optics
- The European Southern Observatory
- Interferometric Astronomy
- Still Bigger Telescopes



The VLT Interferometer with ANTU and MELIPAL

ESO PR Photo 30a/01 (5 November 2001)

Figure 1: Saturn VLT Yepun ESO 31 Jan 2002

Relativistic Heavy Ion Collider (RHIC)

- Gold atoms are stripped of all their electrons
- Beams of gold ions are collided head-on at relativistic speeds ($\sim 99.95\%$ of the speed of light)
- Colliding gold ions produce highly compressed nuclear matter where for a short instant of time the protons and neutrons "melt" to produce a Quark Gluon Plasma (QGP)
- The temperatures and pressures produced are more extreme than even those existing in the hottest of stars
- RHIC produces conditions thought to have existed in the first ten millionth of a second after the Big Bang

From Small to Large to Small

- We have considered lengths ranging from $10^{-35}m$ to $10^{26}m$
- In Particle Physics we look to smaller lengths which takes us back in time to almost the origin of Big Bang. A particle accelerator is a time machine that takes us back in time further than any telescope
- In earlier times Particle Physics and Cosmology were seen as completely unrelated subjects of study
- In the 21st Century it is impossible to separate the two disciplines they have become one and the same subject.

Smaller and Bigger

- Great fleas have little fleas upon their backs to bite 'em,
  And little fleas have lesser fleas, and so ad infinitum.
  And the great fleas themselves, in turn, have greater fleas to go on;
  While these again have greater still, and greater still, and so on.
  De Morgan:*A Budget of Paradoxes*, p. 377
- The greater the circle of our understanding becomes, the greater the circumference of surrounding ignorance
  Erwin Chargaff

...where in the world is the institute of pure research in any department of science with an income of $100,000,000 per year. ... But $100,000,000 per year is but the price of an army or of a navy designed to kill other people. Just think of it, that one per cent of this sum seems to most people too great to save our children and descendants from misery and even death!

But the twentieth century is near - may we not hope for better things before its end? May we not hope to influence the public in this direction?

Henry A. Rowland *The Highest Aim of the Physicist* Presidential Address to the American Physical Society, 28 October 1899.