Introduction to Particle Physics
(for non physics students)
How Old is the Universe?
20.00  Creation Big Bang

world cup 1st half; 2nd half; sleep

05.00  SUN → EARTH  06.00

breakfast; come to lectures

09.30  Oldest Fossils

09.59; 30”  First Humanoids

09.59  The Millenium

10.00  NOW
patterns and structures when cold (low energy)

Symmetry when warm (high energy)
...why didn’t it mutually destruct?
...why is there anything left?
Matter and the Universe

<table>
<thead>
<tr>
<th>Field</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physique des Particules</td>
<td>$10^{-15}$</td>
</tr>
<tr>
<td>Physique Nucleaire</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>Physique du Solide</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>Chimie-Biologie</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Mecanique</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>Geophysique</td>
<td>$10^{3}$</td>
</tr>
<tr>
<td>Astronomie</td>
<td>$10^{6}$</td>
</tr>
<tr>
<td>Astrophysique</td>
<td>$10^{9}$</td>
</tr>
<tr>
<td>Cosmologie</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>Astrophysique</td>
<td>$10^{15}$</td>
</tr>
<tr>
<td>Astronomie</td>
<td>$10^{18}$</td>
</tr>
<tr>
<td>Cosmologie</td>
<td>$10^{21}$</td>
</tr>
</tbody>
</table>

$> 40$ orders of magnitude
What is matter made of?
1. Look

Light source

Object

Eye
1. Look

Light source
Object
Eye
Catch 22:
There’s a limit to what we can see with our eye

Beyond (normal) vision

<table>
<thead>
<tr>
<th>Eye Limit</th>
<th>$10^{-4}$</th>
</tr>
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<tbody>
<tr>
<td>Bacteria</td>
<td>$10^{-5}$</td>
</tr>
<tr>
<td>Wavelength of Light</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Atom</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>Nucleus</td>
<td>$10^{-14}$</td>
</tr>
<tr>
<td>Quarks and Electrons</td>
<td>$10^{-18}$</td>
</tr>
<tr>
<td>Planck Length</td>
<td>$10^{-35}$</td>
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</table>
Catch 22:
There’s a limit to what we can see with our eye.

To look at smaller things we need to use instruments that can “extend” our vision.

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<th>Beyond (normal) vision</th>
<th>10^-4</th>
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<tbody>
<tr>
<td>Eye Limit</td>
<td></td>
</tr>
<tr>
<td>Bacteria</td>
<td>10^-5</td>
</tr>
<tr>
<td>Wavelength of Light</td>
<td>10^-6-7</td>
</tr>
<tr>
<td>Atom</td>
<td>10^-10</td>
</tr>
<tr>
<td>Nucleus</td>
<td>10^-14-15</td>
</tr>
<tr>
<td>Quarks and Electrons</td>
<td>10^-18</td>
</tr>
<tr>
<td>Planck Length ( \sqrt{\frac{Gh}{c^3}} )</td>
<td>10^-35</td>
</tr>
</tbody>
</table>
The problem is the wavelength of light compared with the size of what you’re trying to look at.
How to learn what things are made of

LOOK

resolution

wavelength

How to see small things

light waves

$\lambda \rightarrow 10^{-7}$ m

Electron microscope

electrons

$\lambda = \text{const}/p$

smash

heat

Atom

Atom
2. Smash

How to learn what things are made of

Look, resolution, wavelength, Energy, Temperature
...some definitions for **ENERGY**.

**Joules** are too big for particle energies....

and

0.000000000000000001 Joules is too messy....

So we need more **Practical Units**

eV, keV, MeV, GeV and welcome to TeV
...some definitions for ENERGY

Joules are too big for particle energies....

and

0.0000000000000000001 Joules is too messy....

So we need more Practical Units

eV, keV, MeV, GeV

and welcome to TeV
Einstein

Energy

and

\[ E = mc^2 \]
LOOK or SMASH

Wavelength

and

Energy

profoundly related
LOOK or SMASH

Wavelength

and

Energy

profoundly related
3. Heat

How to learn what things are made of

![Diagram showing concepts related to heat, wavelength, energy, and temperature.]

... also profoundly related......
How to learn what things are made of:

- Resolution
- Wavelength: $\frac{hc}{\lambda}$

SMASH or HEAT

Energy

and

Temperature
SMASH or HEAT
Energy
and
Temperature

$E \propto \frac{h}{\lambda}$

$1 \text{eV} \approx 10^{-4} \text{K}$
How to learn what things are made of

Look

Lasers

Wave length

Resolution

$\frac{hc}{\lambda}$

$10^{-6}$ eV/m

$1$ eV $\rightarrow 10^{-6}$

Smash

Energy

$10^{-4}$ eV K$^{-1}$

$1$ eV $\rightarrow 10^{-4}$ K

Heat

Temperature
Beyond (normal) vision

\[
\begin{array}{c|c|c}
\text{Eye Limit} & 10^{-4} & \text{m} \\
\text{Bacteria} & 10^{-5} \\
\text{Wavelength of Light} & 10^{-6} - 10^{-7} \\
\text{Atom} & 10^{-10} \\
\text{Nucleus} & 10^{-14} - 10^{-15} \\
\text{Quarks and Electrons} & 1 \text{TeV} & 10^{-18} \\
\text{Planck Length} & \frac{\sqrt{Gh}}{c} & 10^{20} \text{ GeV} & 10^{-35}
\end{array}
\]
The Universe in Temperature, Energy, and Time
...and the nature of matter
A Very Short Introduction

Particle Physics
A Very Short Introduction

Frank Close

THE COSMIC ONION
Quarks and the Nature of the Universe

Frank Close

NEW

Coming out in December
Particles in Three Minutes

A quick survey of how we got here....

....and where we think we’re going next.
electrons

Atoms

Photons (Einstein)

The heart of matter in 1905 (Einstein’s great year)
The heart of matter in 1955 (when CERN began)
Electron and Proton utterly different.

proton 2000 times heavier

The heart of matter in 1955 (when CERN began) 10000 times bigger
1955

**ELECTROMAGNETIC** force binds electrons

**FORCES** in the atom

**STRONG** force binds nucleus

**WEAK** force = radioactivity
Cosmic Rays had revealed STRANGE particles.
1955 CERN accelerators replicate cosmic rays on Earth...

..record the images and reveal the real heart of matter....

.....the beginnings of modern high energy particle physics
The heart of matter in 2005 (and even in 2006 !)
Electron and quark very similar in Mass, Size, Spin and in how they respond to the FORCES.

The heart of matter in 2005 (and even in 2006 !)
ELECTROweak force binds electrons

FORCES in the atom

electroWEAK force = radioactivity

Colour QCD force binds quarks
patterns and structures when cold (low energy)

Symmetry when warm (high energy)
Standard Model of Quarks Leptons and forces

= pattern based on mass

“cold” = “low” energy

= below 1 TeV
Standard Model of Quarks Leptons and forces

= pattern based on mass

“cold” = “low” energy

= below 1 TeV

SuperSymmetry when “warm”

(= high energy > 1 TeV)

Higgs Boson
Supersymmetry
Nature of Reality
A Very Short Introduction

Coming out in December

NEW

THE COSMIC ONION
Quarks and the Nature of the Universe
Frank Close
...and patterns (that change)