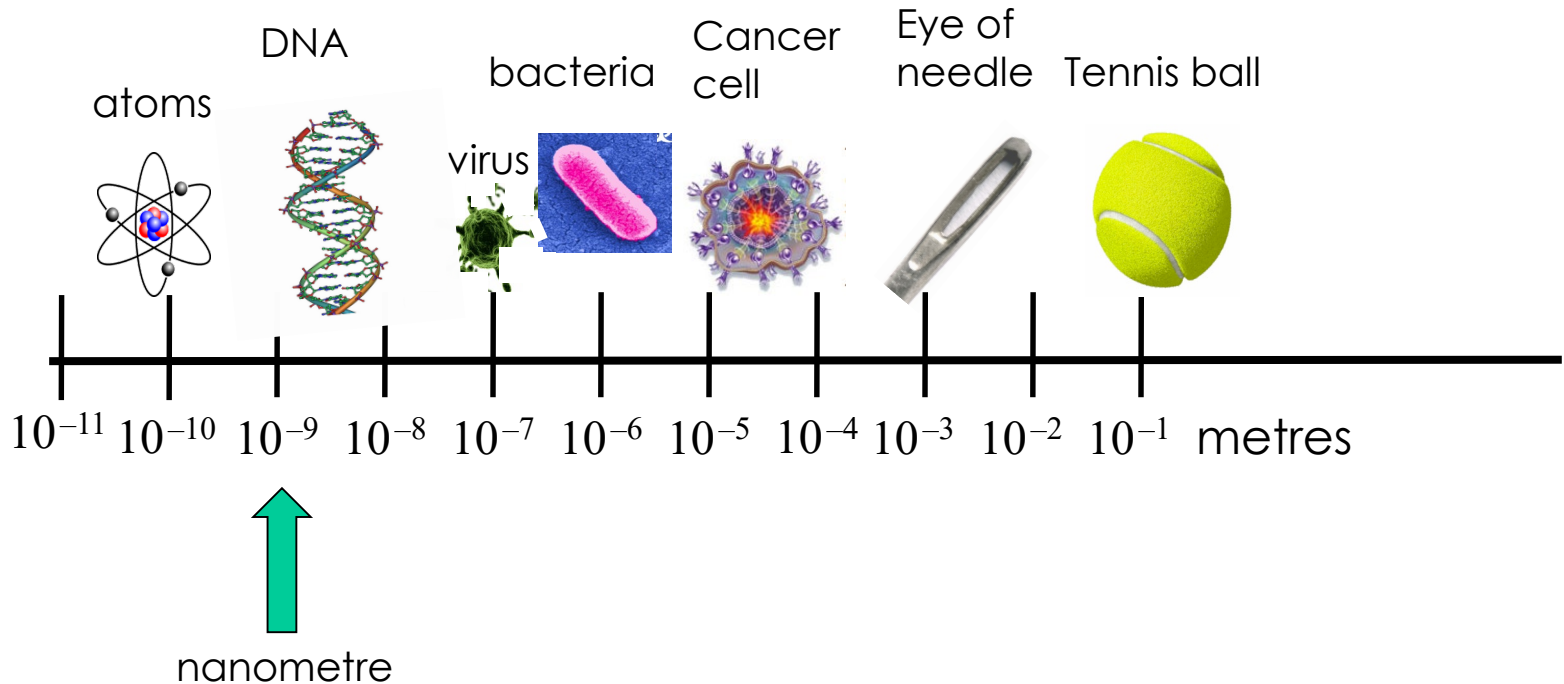


Jim Al-Khalili

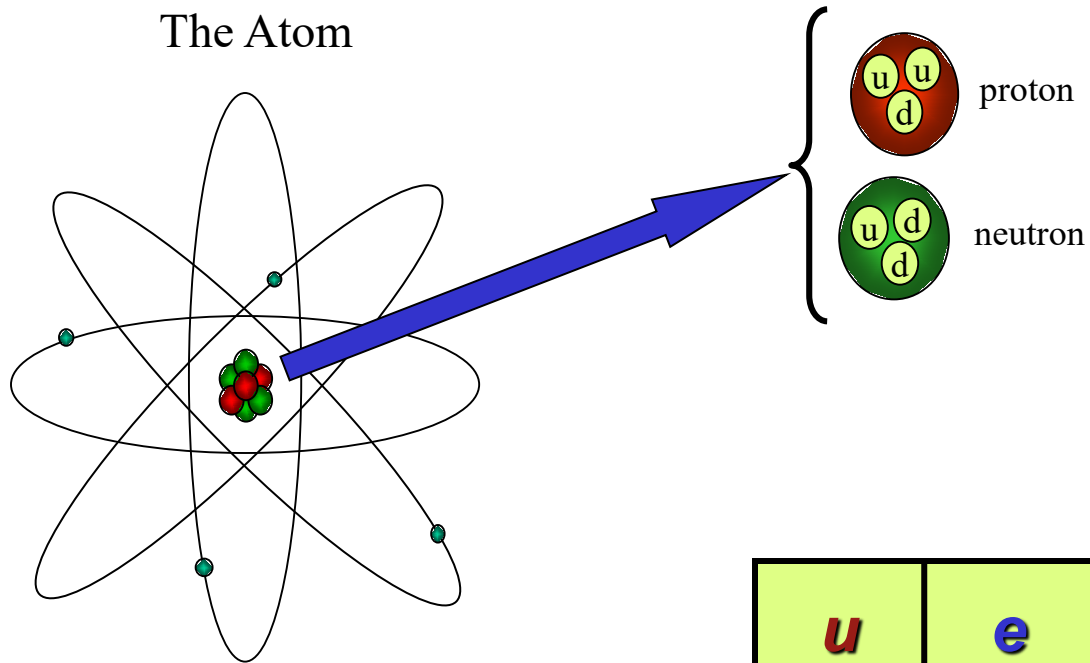
Department of Physics, University of Surrey

But where is the boundary between the
quantum world and the classical world?

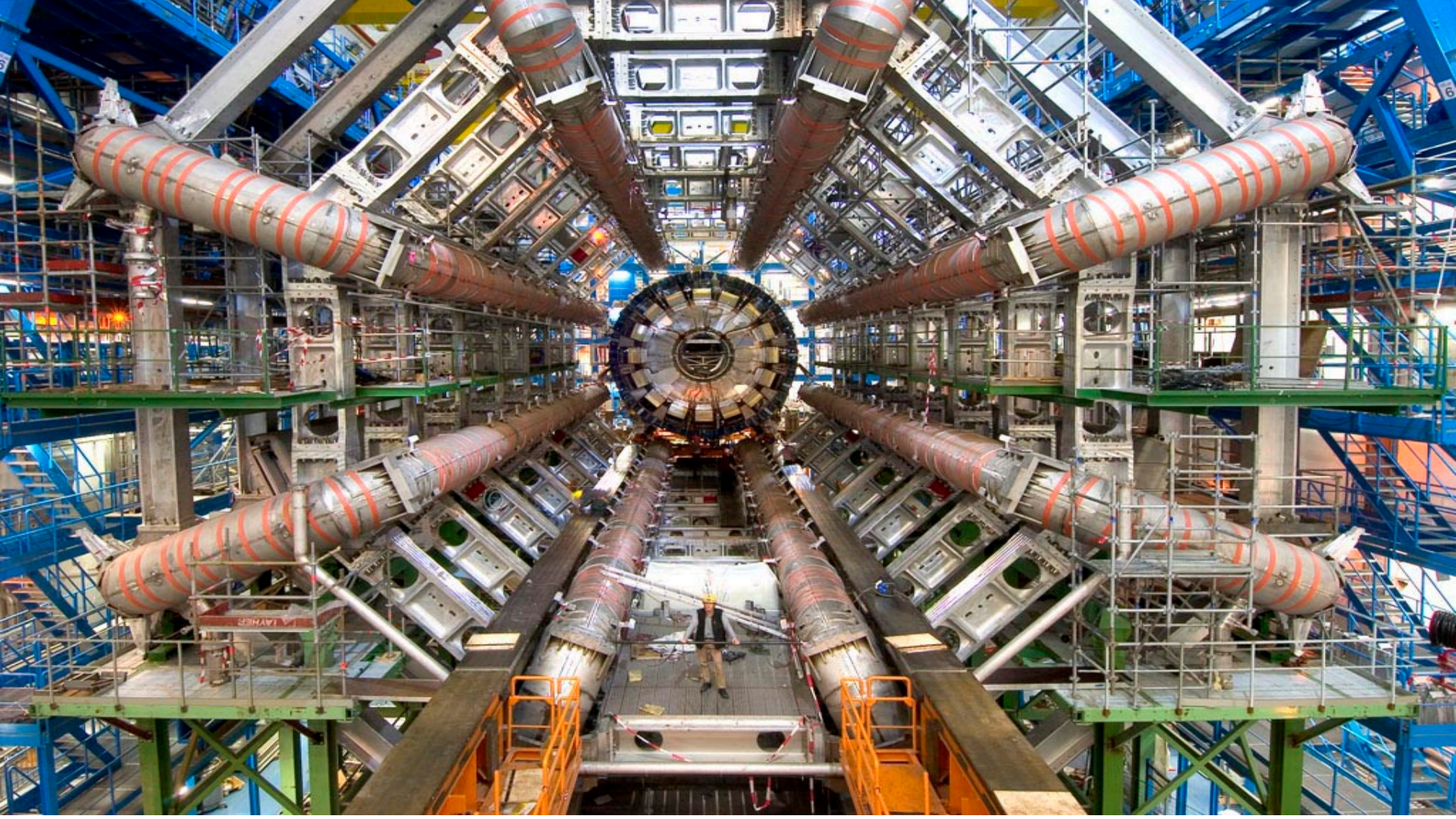
??????????



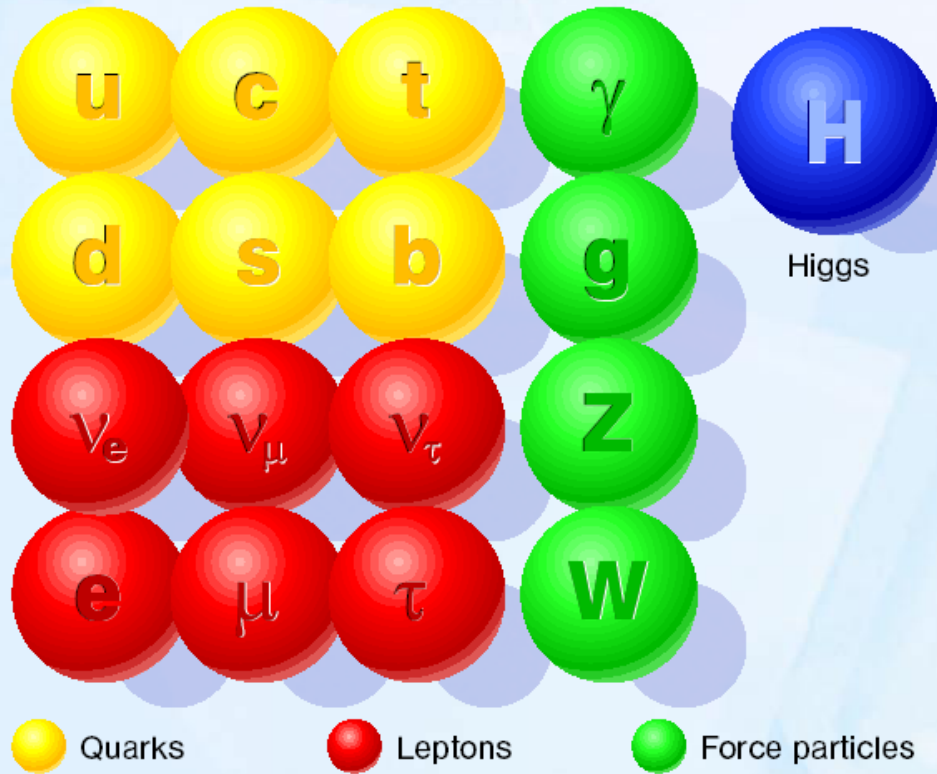
The Atom



<i>u</i>	<i>e</i>
<i>d</i>	ν_e



The Standard Model



Periodic Table of the Elements

Periodic Table of the Elements																		18					
1A 1A																		VIIIA 8A					
1 H Hydrogen 1.008	2 IIA 2A																		2 He Helium 4.003				
3 Li Lithium 6.941	4 Be Beryllium 9.012																	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.99	12 Mg Magnesium 24.305	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948						
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.789						
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294						
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208, 982]	85 At Astatine 208.987	86 Rn Radon 222.018						
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [286]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]						

Lanthanide
Series


Actinide
Series

57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

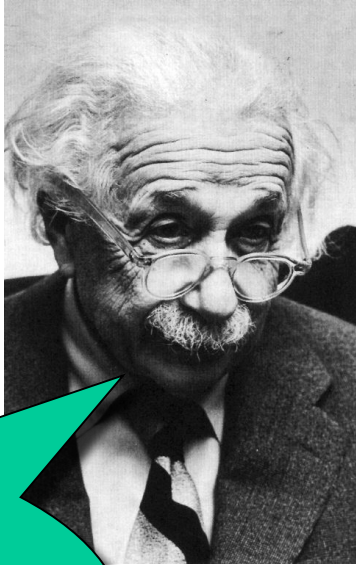
Alkali Metal	Alkaline Earth	Transition Metal	Basic Metal	Semimetal	Nonmetal	Halogen	Noble Gas	Lanthanide	Actinide
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And yet, arguments about what this all means rage to this day



It is wrong to think that the task of physics is to find out how nature **is**. Physics only concerns what we can **find out** about nature.

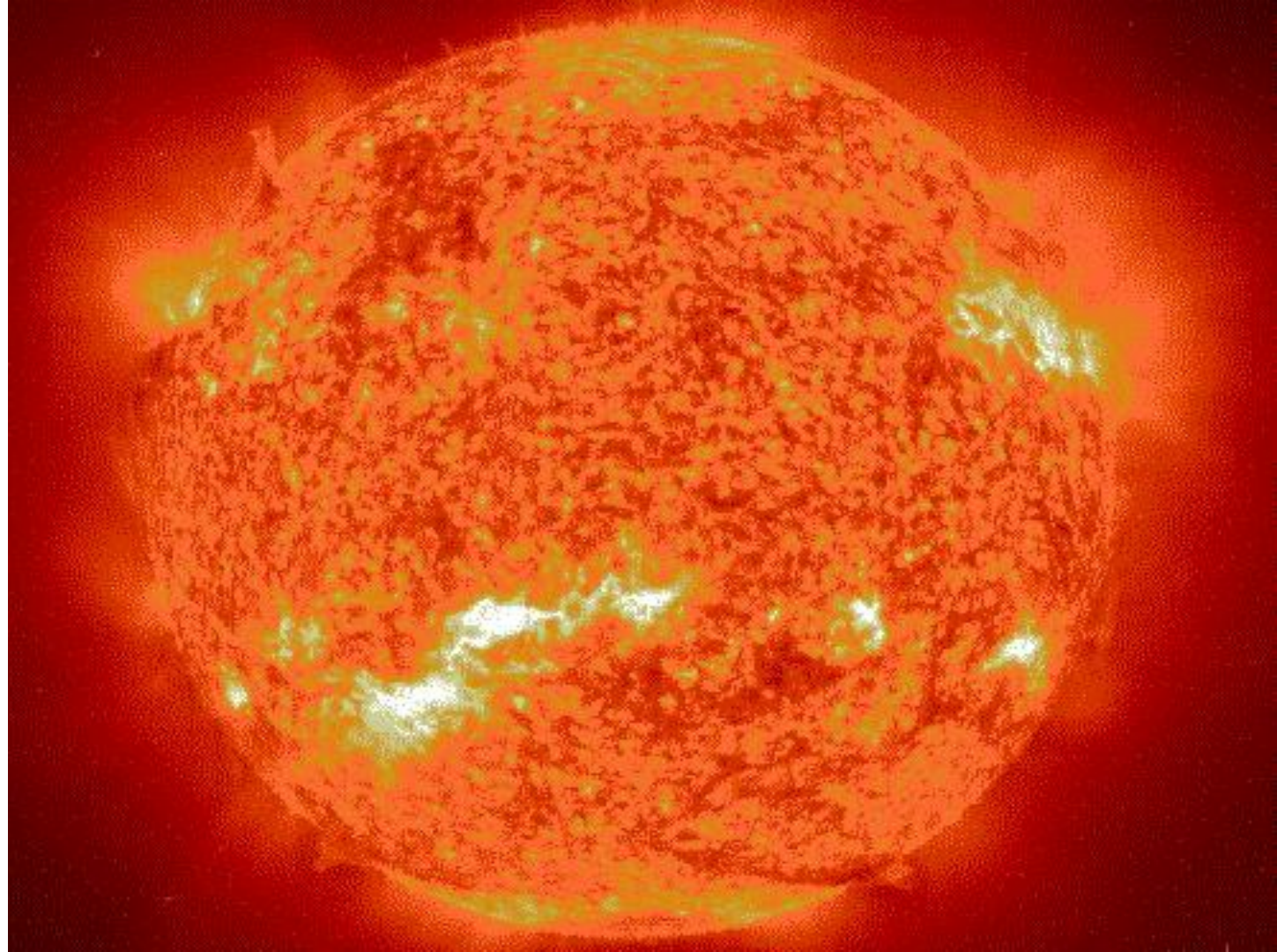


The job of physical theories is to approximate as closely as possible to the truth of **physical reality**.

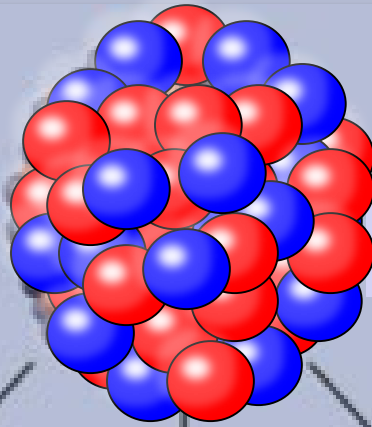
Quantum technologies of the 21st century include quantum computing, quantum sensing, quantum cryptography and even quantum teleportation

Non-trivial quantum phenomena include:

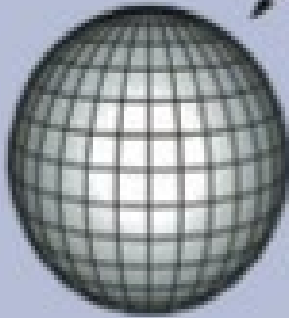
- Long-lived quantum coherence
- Superposition
- Tunnelling
- Entanglement



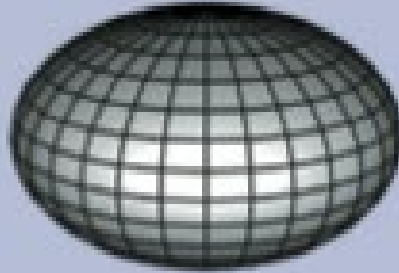
Quantum superposition



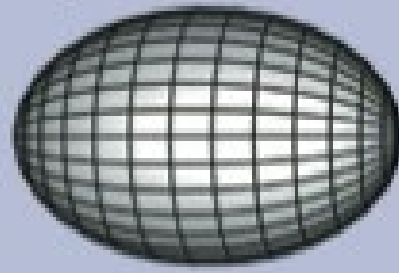
The nucleus of
Lead-186



Spherical



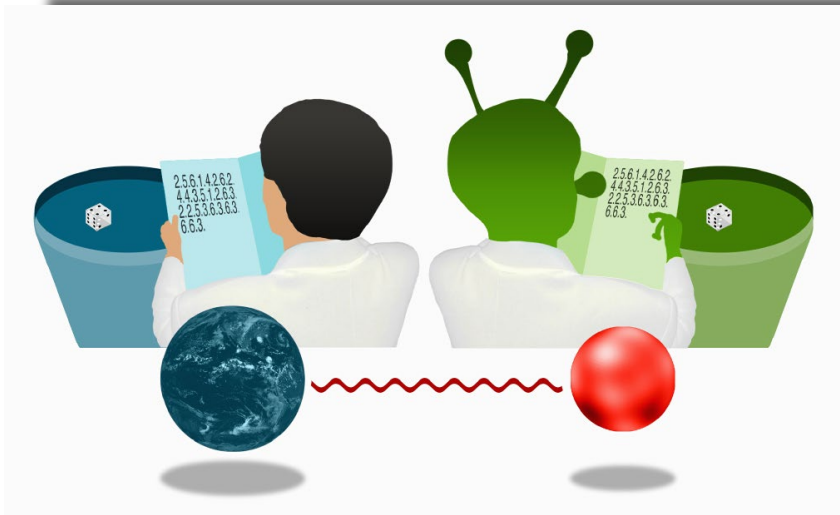
oblate



prolate

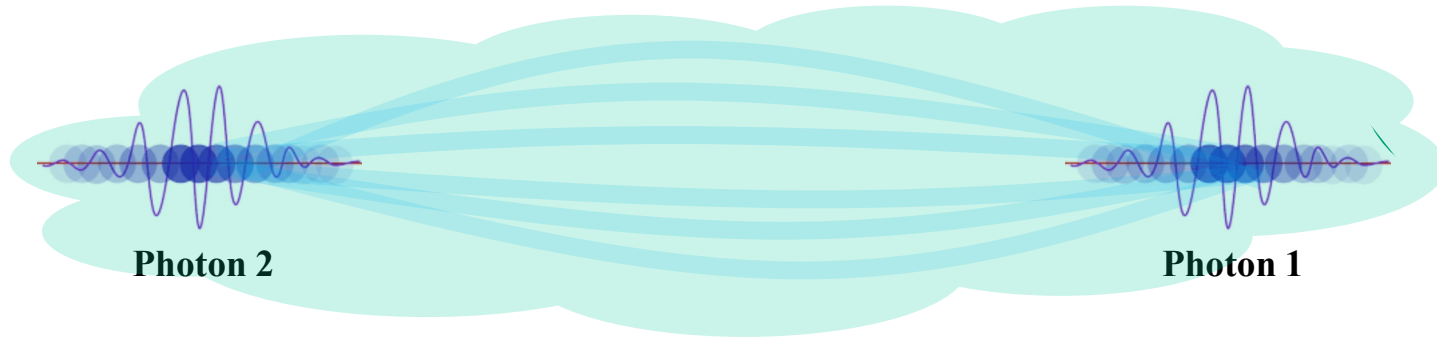
Entanglement

This is due to instantaneous connections between two or more quantum particles which can be very far apart.



The Einstein-Podolski-Rosen Paradox – 1935

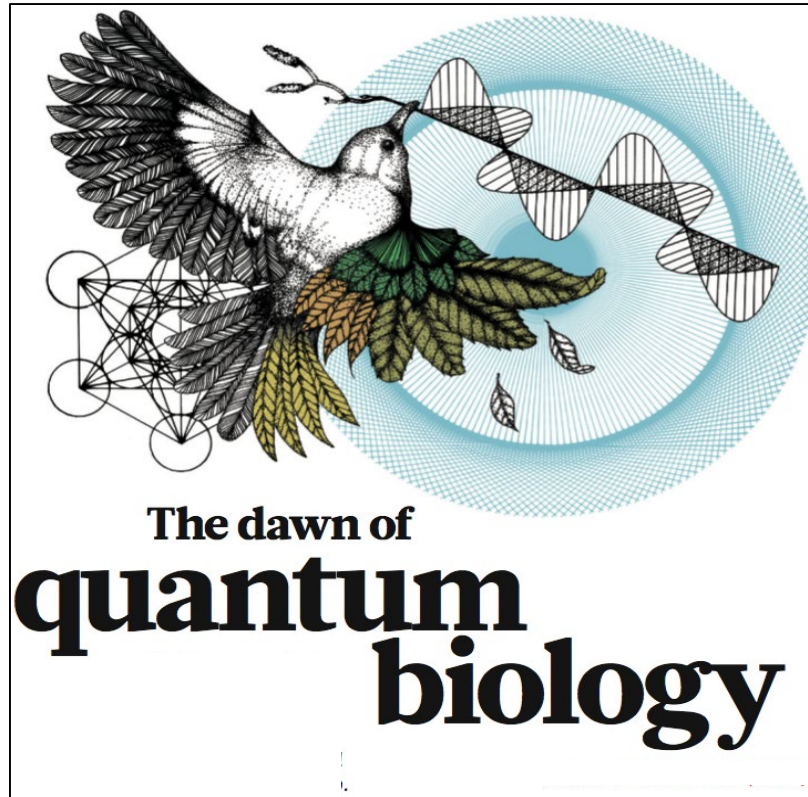
The photons are entangled



Photon 2

Photon 1

An arbitrary distance apart



Article in **Nature** by Philip Ball ([Nature 474 \(2011\) 272-274](#))

2015: The first book on the new field of quantum biology



Co-author, Johnjoe McFadden
(professor of molecular genetics)

So, when did I get involved?



BioSystems 50 (1999) 203–211



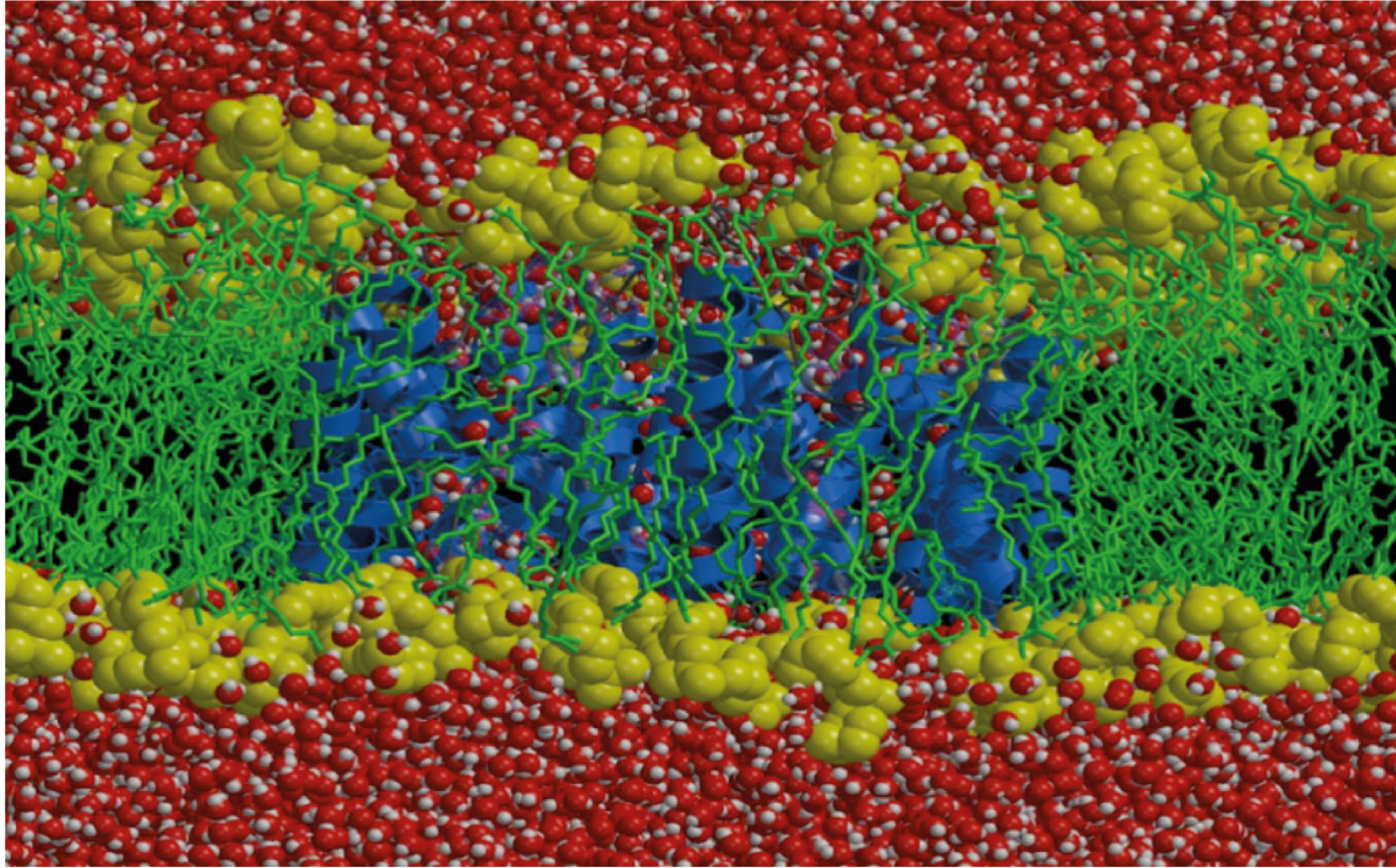
A quantum mechanical model of adaptive mutation

Johnjoe McFadden ^{a,*}, Jim Al-Khalili ^b

^a *Molecular Microbiology Group, School of Biological Sciences, University of Surrey, Guildford, Surrey GU2 5XH, UK*

^b *Department of Physics, University of Surrey, Guildford, Surrey GU2 5XH UK*

Received 10 August 1998; accepted 15 January 1999



Life



Molecular biology



Organic chemistry

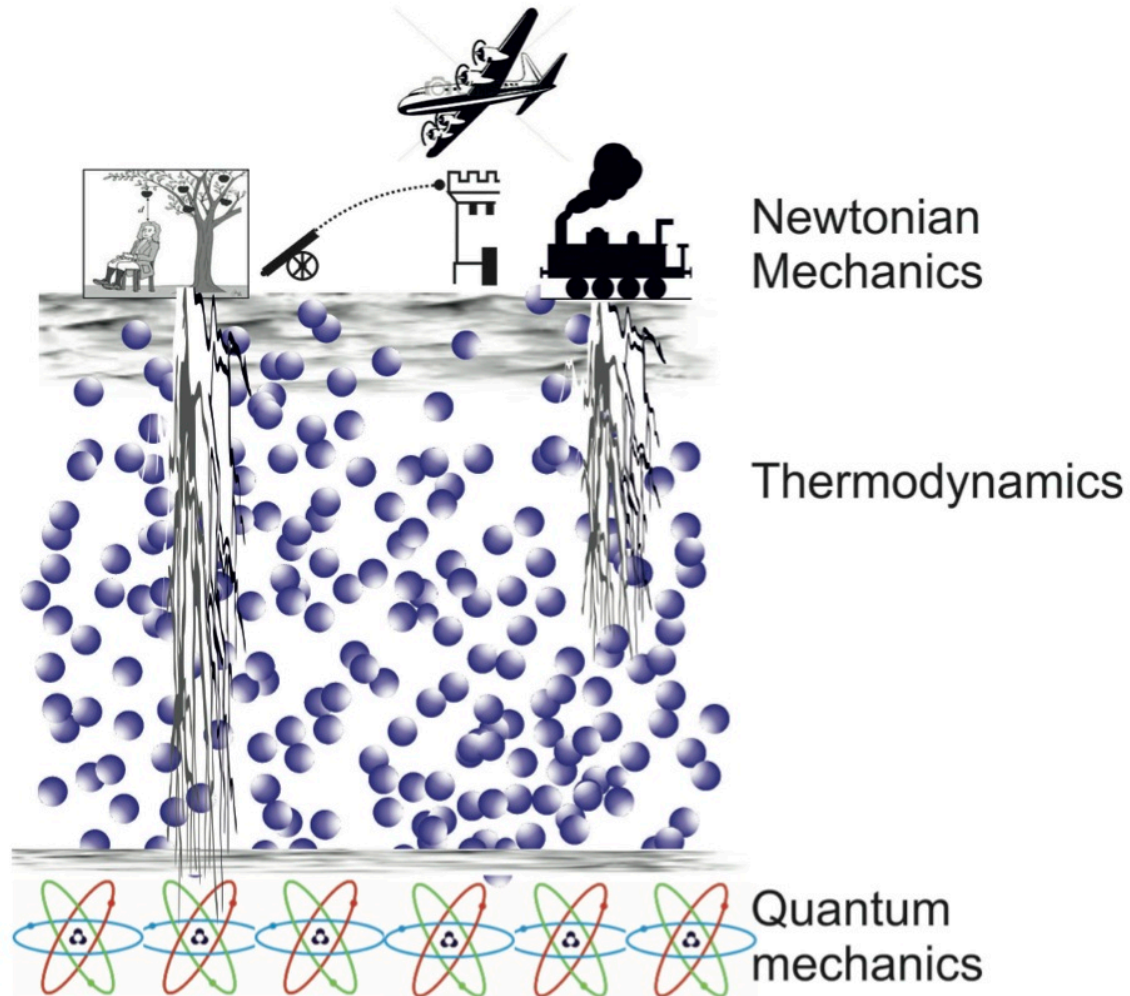


Quantum physics



Quantum superposition
+
Quantum entanglement
=
Schrodinger's cat





Candidates for quantum effects in biology

1. Enzyme action (*confirmed in late 1980s*)
2. Photosynthesis (*well-established*)
3. Magnetoreception in birds (*leading candidate*)
4. How we smell (*gaining respectability*)
5. DNA mutations (*open question*)

Where are we today with quantum biology?

- The field is still in its infancy – it is still speculative;
- There is still widespread skepticism among biologists, mainly surrounding the ‘so what’ question;
- It does appear that certain mechanisms inside living cells require a helping hand from the quantum world;
- We have yet to understand *how* this is possible;
- Has Nature hit upon shortcuts that give it an advantage?
- Can we learn from nature to develop new or more efficient quantum devices?

Quantum biology

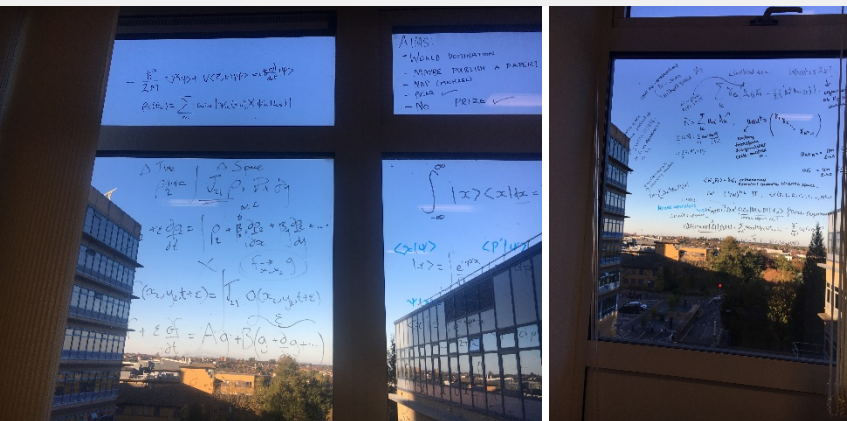
The first new science of the 21st century, quantum biology offers an opportunity to change the way we see the world.

Published: 22 December 2017

PRESS RELEASE

World's first training Centre for Quantum Biology established at the University of Surrey with £1m support from the Leverhulme Trust

The University of Surrey has been awarded £1million from the prestigious **Leverhulme Trust** to establish the world's first doctoral training centre for quantum biology.



If you are not
astonished by
quantum
mechanics then
you have not
understood it!

Niels Bohr

