

The
Emperor's New Mind

*Concerning Computers, Minds, and The
Laws of Physics*

ROGER PENROSE

*Rouse Ball Professor of Mathematics
University of Oxford*

Foreword by
MARTIN GARDNER

Technische Hochschule Darmstadt FACHBEREICH INFORMATIK BIBLIOTHEK Inventar-Nr.:8425..... Sachgebiete: Standort:

OXFORD UNIVERSITY PRESS
OXFORD · NEW YORK · MELBOURNE

Contents

<i>Prologue</i>	1
1 Can a computer have a mind?	3
Introduction	3
The Turing test	5
Artificial intelligence	11
An AI approach to 'pleasure' and 'pain'	14
Strong AI and Searle's Chinese room	17
Hardware and software	23
2 Algorithms and Turing machines	30
Background to the algorithm concept	30
Turing's concept	35
Binary coding of numerical data	42
The Church–Turing Thesis	47
Numbers other than natural numbers	49
The universal Turing machine	51
The insolubility of Hilbert's problem	57
How to outdo an algorithm	64
Church's lambda calculus	66
3 Mathematics and reality	74
The land of Tor'Bled-Nam	74
Real numbers	80
How many real numbers are there?	82
'Reality' of real numbers	86
Complex numbers	87
Construction of the Mandelbrot set	92
Platonic reality of mathematical concepts?	94
4 Truth, proof, and insight	99
Hilbert's programme for mathematics	99
Formal mathematical systems	102
Gödel's theorem	105
Mathematical insight	108
Platonism or intuitionism?	112
Gödel-type theorems from Turing's result	116
Recursively enumerable sets	118
Is the Mandelbrot set recursive?	124
Some examples of non-recursive mathematics	129
Is the Mandelbrot set like non-recursive mathematics?	138
Complexity theory	140
Complexity and computability in physical things	145

5	The classical world	149
	The status of physical theory	149
	Euclidean geometry	156
	The dynamics of Galileo and Newton	162
	The mechanistic world of Newtonian dynamics	167
	Is life in the billiard-ball world computable?	170
	Hamiltonian mechanics	174
	Phase space	176
	Maxwell's electromagnetic theory	184
	Computability and the wave equation	187
	The Lorentz equation of motion; runaway particles	188
	The special relativity of Einstein and Poincaré	191
	Einstein's general relativity	202
	Relativistic causality and determinism	211
	Computability in classical physics: where do we stand?	216
	Mass, matter, and reality	217
6	Quantum magic and quantum mystery	225
	Do philosophers need quantum theory?	225
	Problems with classical theory	228
	The beginnings of quantum theory	230
	The two-slit experiment	231
	Probability amplitudes	236
	The quantum state of a particle	243
	The uncertainty principle	248
	The evolution procedures U and R	250
	Particles in two places at once?	251
	Hilbert space	257
	Measurements	260
	Spin and the Riemann sphere of states	264
	Objectivity and measurability of quantum states	268
	Copying a quantum state	269
	Photon spin	270
	Objects with large spin	273
	Many-particle systems	275
	The 'paradox' of Einstein, Podolsky, and Rosen	279
	Experiments with photons: a problem for relativity?	286
	Schrödinger's equation; Dirac's equation	288
	Quantum field theory	289
	Schrödinger's cat	290
	Various attitudes in existing quantum theory	293
	Where does all this leave us?	296
7	Cosmology and the arrow of time	302
	The flow of time	302
	The inexorable increase of entropy	304
	What is entropy?	309
	The second law in action	314
	The origin of low entropy in the universe	317
	Cosmology and the big bang	322

The primordial fireball	326
Does the big bang explain the second law?	328
Black holes	330
The structure of space–time singularities	335
How special was the big bang?	339
8 In search of quantum gravity	348
Why quantum gravity?	348
What lies behind the Weyl curvature hypothesis?	350
Time-asymmetry in state-vector reduction	354
Hawking’s box: a link with the Weyl curvature hypothesis?	359
When does the state-vector reduce?	367
9 Real brains and model brains	374
What are brains actually like?	374
Where is the seat of consciousness?	381
Split-brain experiments	384
Blindsight	386
Information processing in the visual cortex	387
How do nerve signals work?	389
Computer models	392
Brain plasticity	396
Parallel computers and the ‘oneness’ of consciousness	398
Is there a role for quantum mechanics in brain activity?	400
Quantum computers	401
Beyond quantum theory?	402
10 Where lies the physics of mind?	405
What are minds for?	405
What does consciousness actually do?	409
Natural selection of algorithms?	414
The non-algorithmic nature of mathematical insight	416
Inspiration, insight, and originality	418
Non-verbality of thought	423
Animal consciousness?	425
Contact with Plato’s world	426
A view of physical reality	429
Determinism and strong determinism	431
The anthropic principle	433
Tilings and quasicrystals	434
Possible relevance to brain plasticity	437
The time-delays of consciousness	439
The strange role of time in conscious perception	442
Conclusion: a child’s view	447
<i>Epilogue</i>	451
<i>References</i>	452
<i>Index</i>	461