Roger Penrose

THE EMPEROR'S NEW MIND

Concerning Computers, Minds and The Laws of Physics

FOREWORD BY Martin Gardner



CONTENTS

	Protogue	1
1	CAN A COMPUTER HAVE A MIND?	3
	Introduction	3
	The Turing test	6
	Artificial intelligence	14
	An Al approach to 'pleasure' and 'pain'	.17
	Strong AI and Searle's Chinese room	21
	Hardware and software	30
2	ALGORITHMS AND TURING MACHINES	40
	Background to the algorithm concept	40
	Turing's concept	46
	Binary coding of numerical data	56
	The Church—Turing Thesis	61
	Numbers other than natural numbers	65
	The universal Turing machine	67
	The insolubility of Hilbert's problem	75
	How to outdo an algorithm	83
	Church's lambda calculus	86
3	MATHEMATICS AND REALITY	98
	The land of Tor'Bled-Nam	98
	Real numbers	105
	How many real numbers are there?	108
	'Reality' of real numbers	112
	Complex numbers	114

THE EMPEROR'S NEW MIND

	Construction of the Mandelbrot set	120
	Platonic reality of mathematical concepts?	123
	•	
4	TRUTH, PROOF, AND INSIGHT	129
	Hilbert's programme for mathematics	129
	Formal mathematical systems	133
	Gödel's theorem	138
	Mathematical insight	141
	Platonism or intuitionism?	146
	Gödel-type theorems from Turing's result	151
	Recursively enumerable sets	155
	Is the Mandelbrot set recursive?	161
	Some examples of non-recursive mathematics	168
	Is the Mandelbrot set like non-recursive mathematics?	177
	Complexity theory	181
	Complexity and computability in physical things	188
5	THE CLASSICAL WORLD	193
	The status of physical theory	193
	Euclidean geometry	202
	The dynamics of Galileo and Newton	209
	The mechanistic world of Newtonian dynamics	217
	Is life in the billiard-ball world computable?	220
	Hamiltonian mechanics	225
	Phase space	228
	Maxwell's electromagnetic theory	238
	Computability and the wave equation	243
	The Lorentz equation of motion; runaway particles	244
	The special relativity of Einstein and Poincaré	248
	Einstein's general relativity	261
	Relativistic causality and determinism	273
	Computability in classical physics: where do we stand?	278
	Mass, matter, and reality	280
6	QUANTUM MAGIC AND QUANTUM MYSTERY	291
	Do philosophers need quantum theory?	291
	Problems with classical theory	295
	The heginnings of quantum theory	207

CONTENTS

	The two-slit experiment	299
	Probability amplitudes	306
	The quantum state of a particle	314
	The uncertainty principle	321
	The evolution procedures U and R	323
	Particles in two places at once?	325
	Hilbert space	332
	Measurements	336
	Spin and the Riemann sphere of states	341
	Objectivity and measurability of quantum states	346
	Copying a quantum state	348
	Photon spin	349
	Objects with large spin	353
	Many-particle systems	355
	The 'paradox' of Einstein, Podolsky, and Rosen	361
	Experiments with photons: a problem for relativity?	369
	Schrödinger's equation; Dirac's equation	372
	Quantum field theory	374
	Schrödinger's cat	375
	Various attitudes in existing quantum theory	379
	Where does all this leave us?	383
7	COSMOLOGY AND THE ARROW OF TIME	391
	The flow of time	391
	The inexorable increase of entropy	394
	What is entropy?	400
	The second law in action	407
	The origin of low entropy in the universe	411
	Cosmology and the big bang	417
	The primordial fireball	423
	Does the big bang explain the second law?	426
	Black holes	427
	The structure of space-time singularities	435
	How special was the big bang?	440
8	IN SEARCH OF QUANTUM GRAVITY	450
	Why quantum gravity?	450
	What lies behind the Weyl curvature hypothesis?	453

7

THE EMPEROR'S NEW MIND

	Time-asymmetry in state-vector reduction Hawking's box: a link with the Weyl curvature	458
	hypothesis?	465
	When does the state-vector reduce?	475
9	REAL BRAINS AND MODEL BRAINS	483
	What are brains actually like?	483
	Where is the seat of consciousness?	492
	Split-brain experiments	496
	Blindsight	499
	Information processing in the visual cortex	500
	How do nerve signals work?	502
	Computer models	507
	Brain plasticity	512
	Parallel computers and the 'oneness' of consciousness	514
	Is there a role for quantum mechanics in brain activity?	516
	Quantum computers	518
	Beyond quantum theory?	520
10	WHERE LIES THE PHYSICS OF MIND?	523
	What are minds for?	523
	What does consciousness actually do?	529
	Natural selection of algorithms?	534
	The non-algorithmic nature of mathematical insight	538
	Inspiration, insight, and originality	541
	Non-verbality of thought	548
	Animal consciousness?	550
	Contact with Plato's world	552
	A view of physical reality	555
	Determinism and strong determinism	558
	The anthropic principle	560
	Tilings and quasicrystals	562
	Possible relevance to brain plasticity	566
	The time-delays of consciousness	568
	The strange role of time in conscious perception	573
	Conclusion: a child's view	578
	Epilogue	583

CONTENTS

References	584
Index	596