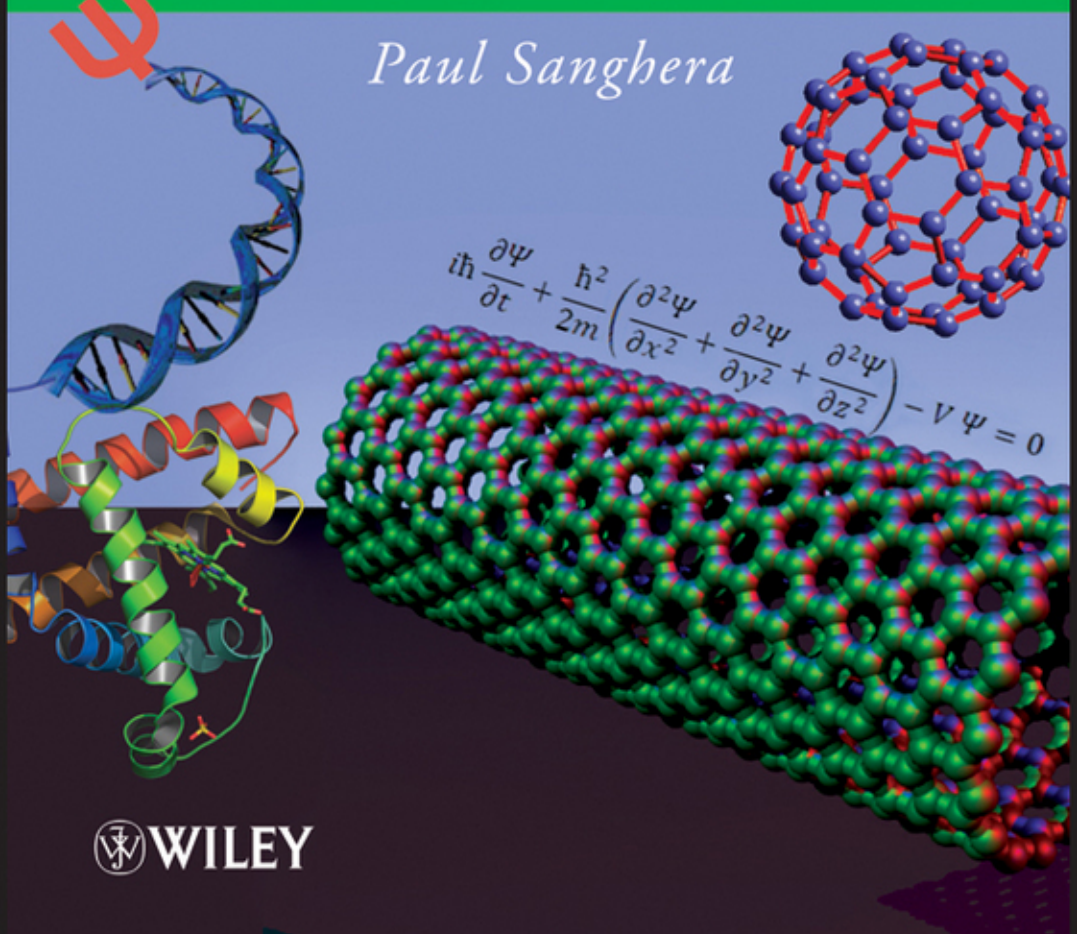
Quantum Physics for Scientists and Technologists

Fundamental Principles and Applications for Biologists, Chemists, Computer Scientists, and Nanotechnologists

Paul Sanghera



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QUANTUM PHYSICS FOR SCIENTISTS AND TECHNOLOGISTS

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Fundamental Principles and Applications for Biologists, Chemists, Computer Scientists, and Nanotechnologists

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To scores of my teachers, thousands of my students,
and hundreds of my colleagues all across the globe from whom
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Contents

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About the Author

Dr. Paul Sanghera, an educator, scientist, technologist, and an entrepreneur, has a diverse background in major fields on which nanoscience and nanotechnology is based including physics, chemistry, biology, computer science, and math. He holds a Ph.D. in Physics from Carleton University, Canada; a Master degree in Computer Science from Cornell University, U.S.A; and a B.Sc. from India with triple major: physics, chemistry, and math. He has authored and co-authored more than 100 research papers on the subatomic particles of matter published in well-reputed European and American research journals. At the world class laboratories, such as CERN in Europe and Nuclear Lab at Cornell, he has participated in designing and conducting experiments to test the quantum theories and models of subatomic particles. His current research interests involve topics in biotechnology, biochemistry, and molecular biology. In computer science, Dr. Sanghera has contributed to building such world class technologies as Netscape Communicator and Novell's NDS. As an engineering manager, he has been at the ground floor of several startups. A former lecturer at San Jose State University, he has taught a wide spectrum of courses at institutions all across the globe including India, Canada, and the United States. Dr. Sanghera is the author of several best selling books in the fields of science, technology, and project management. He lives in Silicon Valley, California.

About the Tech Editor

Dr. John Serri has held a variety of positions from basic physics research to application software development. His broad industrial and academic experience enabled him to develop a rigorous yet practical perspective to physics. Serri received his BS degree in Math and Physics from the State University of New York (SUNY) at Albany and earned a Ph.D. in Physics from the Massachusetts Institute of Technology where he developed novel techniques for using lasers to probe the dynamics of intermolecular collisions. The techniques he developed have led to numerous applications in basic physics including laser cooling, which led one of his mentors, Dr. William Phillips, to the Nobel Prize in Physics in 1997. After leaving MIT, Dr. Serri joined the staff at Bell Laboratories, where he conducted basic research in surface physics and applied research related to the effects of nuclear weapons on telecommunication systems. Later he joined the staff of Loral Aerospace and was one of the designers of the Globalstar System. At Globalstar, he led the development of the systems to control and manage the Globalstar network. Serri currently serves on the adjunct faculty of the Mathematics and Computer Science Department at California State University East Bay and is Vice President of Strategic Inititives at Manhattan Software Inc., a major provider of Advanced Integrated enterprise software.

Periodic Table of the Elements

Period	Group 1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 vIIIA 8A
1	1 H 1.008																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.47	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
6	55 Cs 132.9	56 Ba 137.3	57 La* 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 190.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.5	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (257)	105 Db (260)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 — ()	111 — ()	112 — ()		114 — ()		116 — ()		118 — ()

Lanthanide Series	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (147)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
Actinide Series	90 Th 232.0	91 Pa (231)	92 U (238)	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lr (257)

Fundamental Physical Constants[a]

Quantity	Symbol	Value(s)
Atomic mass unit or Dalton	amu, u, Da	$1.660538782 \times 10^{-27}$ kg
		931.494028×10^{6} eV/c^2
Avogadro number	L, N_A	$6.02214179 \times 10^{23}$ mol^{-1}
Boltzmann constant	k	$1.3806504 \times 10^{-23}$ J K^{-1}
Elementary charge	e	$1.602176487 \times 10^{-19}$ C
Gravitational constant	G	6.67428×10^{-11} m^3 kg^{-1} s^{-2}
Mass of electron	m_e	$9.10938215 \times 10^{-31}$ kg
		$8.18710438 \times 10^{-14}$ J/c^2
		0.510998910 MeV/c^2
		$5.4857990943 \times 10^{-4}$ u
Mass of proton	m_p	$1.672621637 \times 10^{-27}$ kg
		$1.503277359 \times 10^{-10}$ J/c^2
		938.272013 MeV
		1.00727646677 u
Molar gas constant	R	8.314472 J K^{-1} mol^{-1}
		0.08205746 L atm K^{-1} mol^{-1}
		K for kelvin
Permeability of vacuum	μ_0	$4\pi \times 10^{-7}$ N A^{-2}
Magnetic constant		N for newton and A for ampere.
Permittivity of vacuum	ϵ_0	$8.854187817 \times 10^{-12}$ F m^{-1}
Electric constant		
Planck constant	h	$6.62606896 \times 10^{-34}$ J s
		$4.13566733 \times 10^{-15}$ ev s
		$6.62606896 \times 10^{-27}$ erg s
Speed of light in vacuum	c	2.99792458×10^{8} m/s
Stefan-Boltzmann constant	σ	5.670400×10^{-8} W m^{-2} K^{-4}
		W for watt

[a] Courtesy of the National Institute of Standards and Constants (NIST).

Important Combinations of Physical Constants

Quantity	Symbol	Value(s)
Bohr magneton	$\mu_B = \dfrac{e\hbar}{2m_e}$	$927.400915 \times 10^{-26}\,\mathrm{J\,T^{-1}}$
Bohr radius	$a_0 = \dfrac{4\pi\varepsilon_0\hbar^2}{m_e e^2}$	$0.52917720859 \times 10^{-10}\,\mathrm{m}$
Compton wavelength	$\lambda_c = \dfrac{h}{m_e c}$	$2.4263102175 \times 10^{-12}\,\mathrm{m}$
Molar gas constant	$R = N_A k$	$8.314472\,\mathrm{J\,K^{-1}\,mol^{-1}}$ $0.08205746\,\mathrm{L\,atm\,K^{-1}\,mol^{-1}}$
Rydberg constant	$\Re_\infty = \dfrac{me^4}{4\pi c\hbar^3(4\pi\varepsilon_0)^2}$	$1.0973731568527 \times 10^{-7}\,\mathrm{m^{-1}}$
Speed of light	$c = \dfrac{1}{\sqrt{\varepsilon_0\mu_0}}$	$2.99792458 \times 10^{8}\,\mathrm{m/s}$
—	$\dfrac{1}{4\pi\varepsilon_0}$	$8.98755 \times 10^{9}\,\mathrm{m\,F^{-1}}$ F for farad, a unit of capacitance
—	$\hbar = \dfrac{h}{2\pi}$	$1.054571628 \times 10^{-34}\,\mathrm{J\,s}$ $6.58211899 \times 10^{-16}\,\mathrm{eV\,s}$
—	hc	$1.9864 \times 10^{-25}\,\mathrm{J\,m}$ $1239.8\,\mathrm{eV\,nm}$
—	$\hbar c$	$3.1615 \times 10^{-26}\,\mathrm{J\,m}$ $197.33\,\mathrm{eV\,nm}$

Preface
Science, Technology, and Quantum Physics: Mind the Gap

Quantum physics thus reveals a basic oneness of the universe.

Erwin Schrodinger

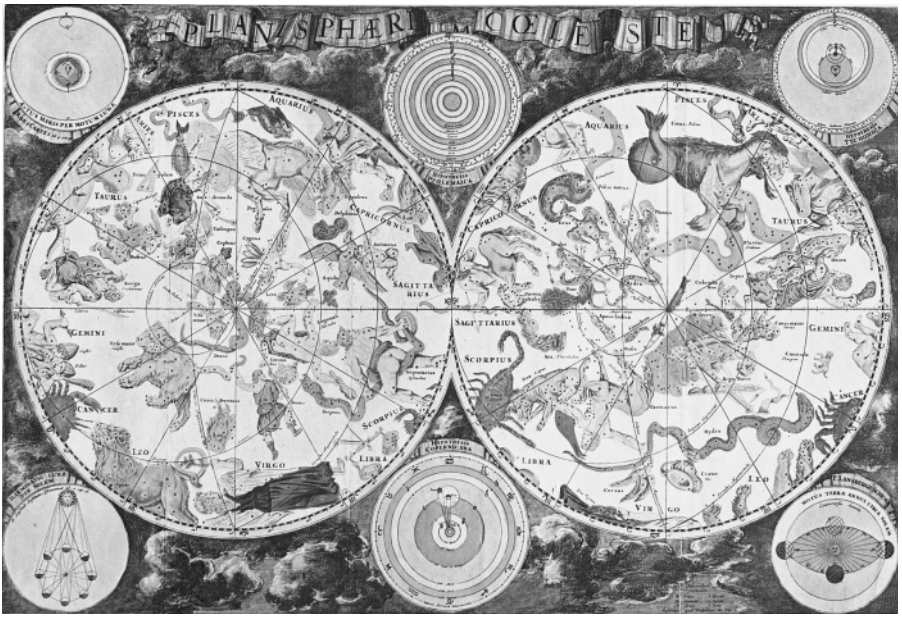

Figure P.1 Celestial map from the seventeenth century, by the Dutch cartographer Frederik de Wit (1630–1698).

In This Preface

To an artist, in Shakespeare's words, All the world's a stage. Taking this metaphor to another level, to a scientist, the whole universe is a colossal party with a cosmic dance on dance floors at all levels, ranging from an expanding universe with swirling galaxies, to planets revolving around their suns, to organisms of all shapes and sizes dancing through their life cycles, to molecules in action inside living and nonliving systems, to atoms making and breaking bonds to make molecules and crystals, to electrons dancing around the nucleus of atoms, and so on. The universe and everything in it, living and nonliving, originally started (and still starts) at the microscopic level, a level too small for human senses to resolve. In this book, we focus on the concept of micro in contrast to that of macro; micro means anything small enough not to be seen by the naked eye, including the size scales of micrometers, nanometers, and smaller items. Because the universe and everything in it is comprised of microentities, to fully understand the macro we need to understand the micro.

Humans, the macrobeings, have evolved to a relatively advanced level. For better or for worse we are late comers to this party of life on Earth. On the scale of a 12-h clock, if the party started at the hour zero (i.e., midnight) with the solidification of the earth's crust, and if it is noon now, we have just arrived at 11:59:59. However, now that we have arrived, we are the most curious and ambitious creatures at the party. We want to know everything about everyone and everything in the party: Who (or what) are you? What are you made of? How did you get here? Where are you from, no I mean where are you originally from? Where are you headed, that is, what is your future?

All the answers accumulated from our age old queries have uncovered the three most important higher-level secrets of nature, important and general enough that they should become part of the thinking of scientists and students of all sciences.

P.1 THREE SECRETS OF NATURE

At first glance, the diversity around us is obvious and ubiquitous. However, during the entire history of the development of science, the history of discoveries and inventions, nature has taught us a very powerful lesson over and over again: Look for the underlying unity behind apparent diversity of things and phenomena, and therefore behind the laws governing those things and phenomena. In my opinion, the three most salient of all the secrets of nature that science has discovered so far are the following:

There Is an Underlying Unity Behind Apparent Diversity. This concept is a key point to understanding not only the things and phenomena around us, but also their diversity. For example, all life is made up of the same basic building block of life: the cell. Most great discoveries and breakthroughs in the history of science have revealed this secret over and over again: unity behind diversity.