SCIENCE

PRAISE FOR

ESCAPE FROM SHADOW PHYSICS

"In the bouncing groove of an oil droplet, Adam Forrest Kay finds a new way to look at quantum mechanics—one that replaces randomness and mystery with new knowledge. Supported by a brilliantly told history and philosophy of physics, this book will change how you think about the field's past. And it may just set a new path for its future."

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ESCAPE FROM SHADOW PHYSICS

THE QUEST TO END THE DARK AGES OF QUANTUM THEORY

KAY

BASIC

ESCAPE FROM SHADOW PHYSICS

THE QUEST TO END THE DARK AGES OF QUANTUM THEORY

ADAM FORREST KAY

Escape from Shadow Physics *in nuce*

What I learned researching a whole book on QM

Adam Kay 2023-03-20

Plan

- Formal and cultural relation between thermodynamics and QM
- Bell’s Theorem


What is heat?

Thermo and QM

Vibration

- One view was that heat was vibration, a *state* of matter, a modification thereof, not a form of matter itself.
- Newton, Hooke, Boyle and Locke were all of the view that heat is motion.
- The theory was hard to develop, for a long time nobody could do better than Boyle's description: "various, vehement, and intestine commotion of the parts among themselves."

Thermo and QM

Caloric

- Dominant view of heat through 1700s and through 1820 was the theory of caloric (from Latin *calor,* heat)
- “Caloric” was a physical entity, on par with oxygen and hydrogen. Thus the caloric theory was sometimes called the *chemical* theory of heat.
- Caloric particles are invisible, light (or weightless), and self repulsive. They permeate the finest pores of matter.

ELEMENTS OF CHEMISTRY,

IN A

NEW SYSTEMATIC ORDER,

CONTAINING ALL THE

MODERN DISCOVERIES.

ILLUSTRATED WITH THIRTEEN COPPERPLATES.

BY MR LAVOISIER,

Member of the Academy of Sciences, Royal Society of Medicine, and Agricultural Society of Paris, of the Royal Society of London, and Philosophical Societies of Orleans, Bologna, Basil, Philadelphia, Haerlem, Manchester, &c. &c.

TRANSLATED FROM THE FRENCH,

BY ROBERT KERR, F.R. & A.SS.E.

Member of the Royal College of Surgeons, and Surgeon to the Orphan Hospital of Edinburgh.

EDINBURGH:

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MDCCXC.

1790

ELEMENTS OF CHEMISTRY.

PART I.

Of the Formation and Decompoſition of Aeriform Fluids—of the Combuſtion of Simple Bodies—and the Formation of Acids.

CHAP. I.

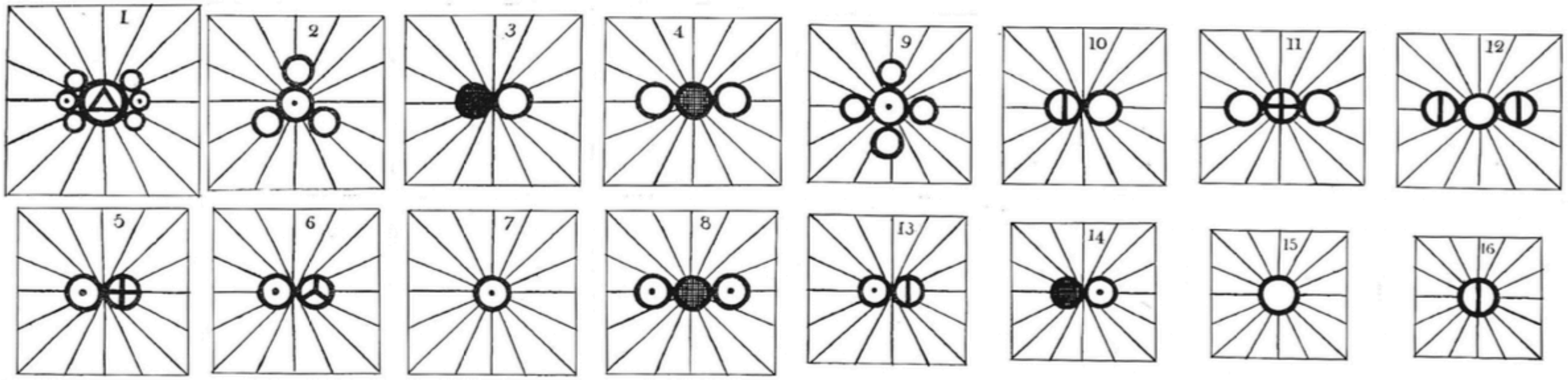
Of the Combinations of Caloric, and the Formation of Elaſtic Aëriform Fluids.

THAT every body, whether ſolid or fluid, is augmented in all its dimenſions by any increaſe of its ſenſible heat, was long ago fully eſtabliſhed as a phyſical axiom, or univerſal propoſition, by the celebrated Boerhaave. Such facts as have been adduced for controverting the

Thermo and QM

Caloric

- p. 82 seq.



Thermo and QM

Heat Equation

$$u_t = \Delta u$$

- In 1804 Fourier (“exiled” in Genoble through a Napoleonic promotion) made a breakthrough on the study of heat.
- Heat equation connects change in time with Laplacian
- Linear equation
- Fundamental solution tool: Fourier series

Thermo and QM

Heat Equation

$$u_t = \Delta u$$

Fourier's book, finally published in 1822, is 639 pages of dense analysis of specific physical situations, composed over almost two decades. The effect it had on the future of mathematics can hardly be overstated. William Rowan Hamilton looked back a century and said this:

> Poisson… does not seem to me to have nearly so logical a mind as Cauchy, great as his talents and clearness are; and both are in my judgment very far inferior to Fourier, whom I place at the head of the French School of Mathematical Philosophy, even above Lagrange and Laplace, though I rank their talents above those of Cauchy and Poisson.

Thermo and QM

Positivism

- Situation in 1822: There was a differential equation that described the behavior of heat, but two different and opposing theories of the nature of heat. Thus, the math worked for an unknown reason.

Thermo and QM

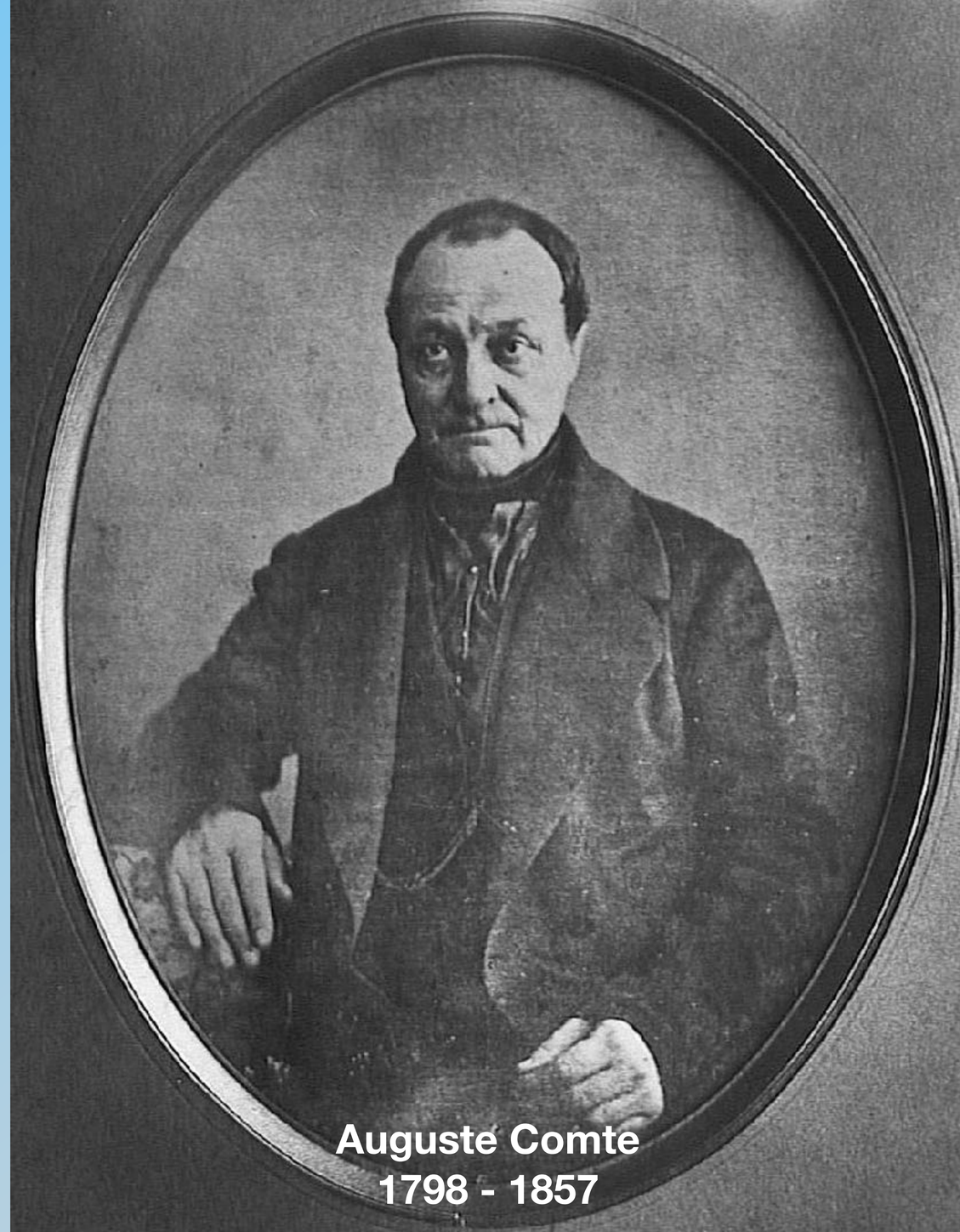
Positivism

- What is positivism?

Thermo and QM

Positivism

- What is positivism?
- pp 86 - 87:
  - The basic idea… false hopes.
- p 90 seq.



Auguste Comte
1798 - 1857

Thermo and QM

Kinetic Theory of Gases

- Illustrations of the Dynamical Theory of Gases 1860

In view of the current interest in the theory of gases proposed by Bernoulli (Selection 3), Joule, Krönig, Clausius (Selections 8 and 9) and others, a mathematical investigation of the laws of motion of a large number of small, hard, and perfectly elastic spheres acting on one another only during impact seems desirable.

It is shown that the number of spheres whose velocity lies between v and $v + dv$ is

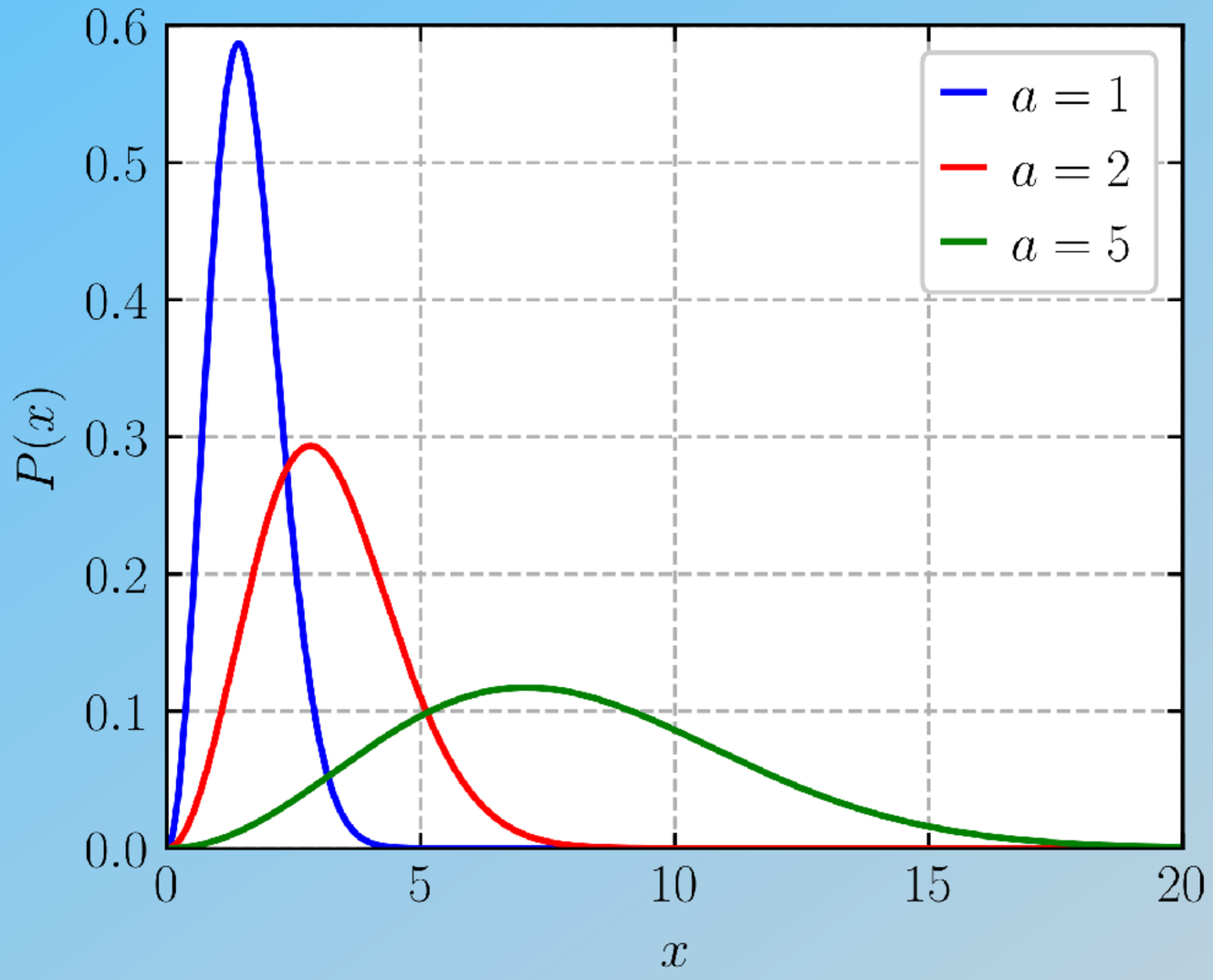
$$N \frac{4}{\alpha^3 \sqrt{\pi}} v^2 e^{-v^2/\alpha^2} dv,$$

where N is the total number of spheres, and α is a constant related to the average velocity:

$$\text{mean value of } v^2 = \tfrac{3}{2} \alpha^2.$$

Thermo and QM

Kinetic Theory of Gases



Thermo and QM

Kinetic Theory of Gases

- Heat is mean molecular kinetic energy, related to Maxwell's alpha.
- Thus it is statistical, its behavior determined by inconceivably many "collisions."
- Anything that operates similarly can be described with the diffusion equation, which is equivalent to the heat equation when the diffusion coefficient is constant.
  - Diffusion of mass (Fick 1855)
  - Diffusion of prices (Bachelier 1900)
  - Blood through capillaries, neutrons through graphite, etc.

Thermo and QM

Review

- Heat equation form
- Multiple interpretations of heat equation
- Positivism
- Heat is statistical

Thermo and QM

Schrödinger Equation

$$\psi_t = i\Delta\psi$$

- In 1925 Schrödinger (on Xmas holiday in Arosa with a mystery woman) made a breakthrough in the study of atoms.
- Schrödinger equation connects change in time with "imaginary Laplacian."
- Linear equation
- Fundamental solution tool: Fourier series

Thermo and QM

$$\psi = f + ig$$

$$\rightarrow$$

$$g_t = \Delta f$$

$$f_t = -\Delta g$$

Thermo and QM

Multiple Interpretations

- There are many interpretations of the Schrödinger equation
- Mermin: “New interpretations appear every year. None ever disappear.”

Thermo and QM

Positivism, Again?

- Epiphany at Heligoland, 1925

> The objective of this work is to lay the foundations for a theory of quantum mechanics based exclusively on relations between quantities that are in principle observable.[3]

- pp 155-seq: These early positivistic…

Thermo and QM

Statistical theory

- Quantum mechanics makes *statistical* predictions only.
- Through Born’s rule the primary theoretical tool in QM is the probability distribution.

Thermo and QM

Here are the main parallels:

- ✅ There were multiple interpretations of the nature of heat, just as there are multiple interpretations of quantum mechanics;
- ✅ Positivists explicitly denied hidden variables would ever be found to explain the heat equation, just as they did in the 20^{th} century (and today) in quantum theory;
- ✅ Both theories are statistical;
- ✅ The heat equation and the Schrödinger equation are extremely close, differing only by a factor of i.

The Choice

- pp 160-162

Bell’s Theorem

Plan

- EPR — Explanation of the problem
- Three assumptions of the theorem
- Bell’s inequality
- Boole and the “fourth assumption”
- Statistical compatibility

Bell’s Theorem

EPR

- In 1935, Einstein, Podolsky and Rosen published “Can Quantum Mechanical Description of Reality be Considered Complete?”
- Einstein’s most cited paper
- Schödinger: “Like a pike in a goldfish pond” — “Caught dogmatic Copenhagen by the coattails.”

Bell’s Theorem

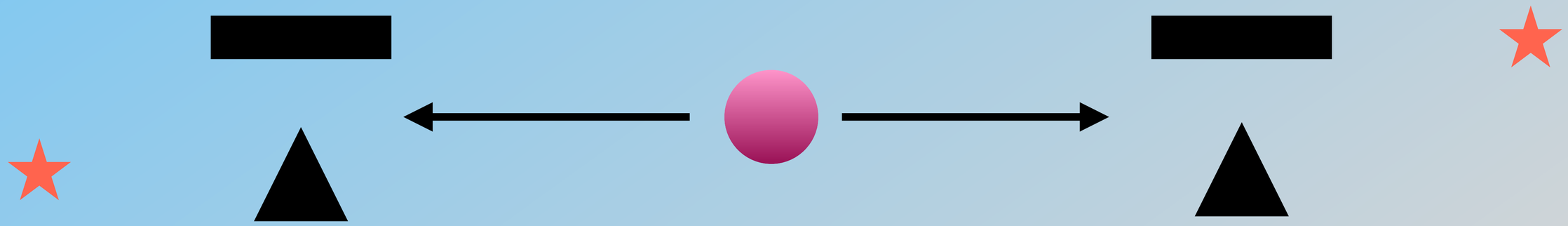
EPR

- EPR criterion of reality: "If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of reality corresponding to that quantity.”
- But QM says nothing about this, only about probabilities, thus it is not complete.
- Here is Bohm’s version of the EPR idea:

Bell's Theorem

EPR

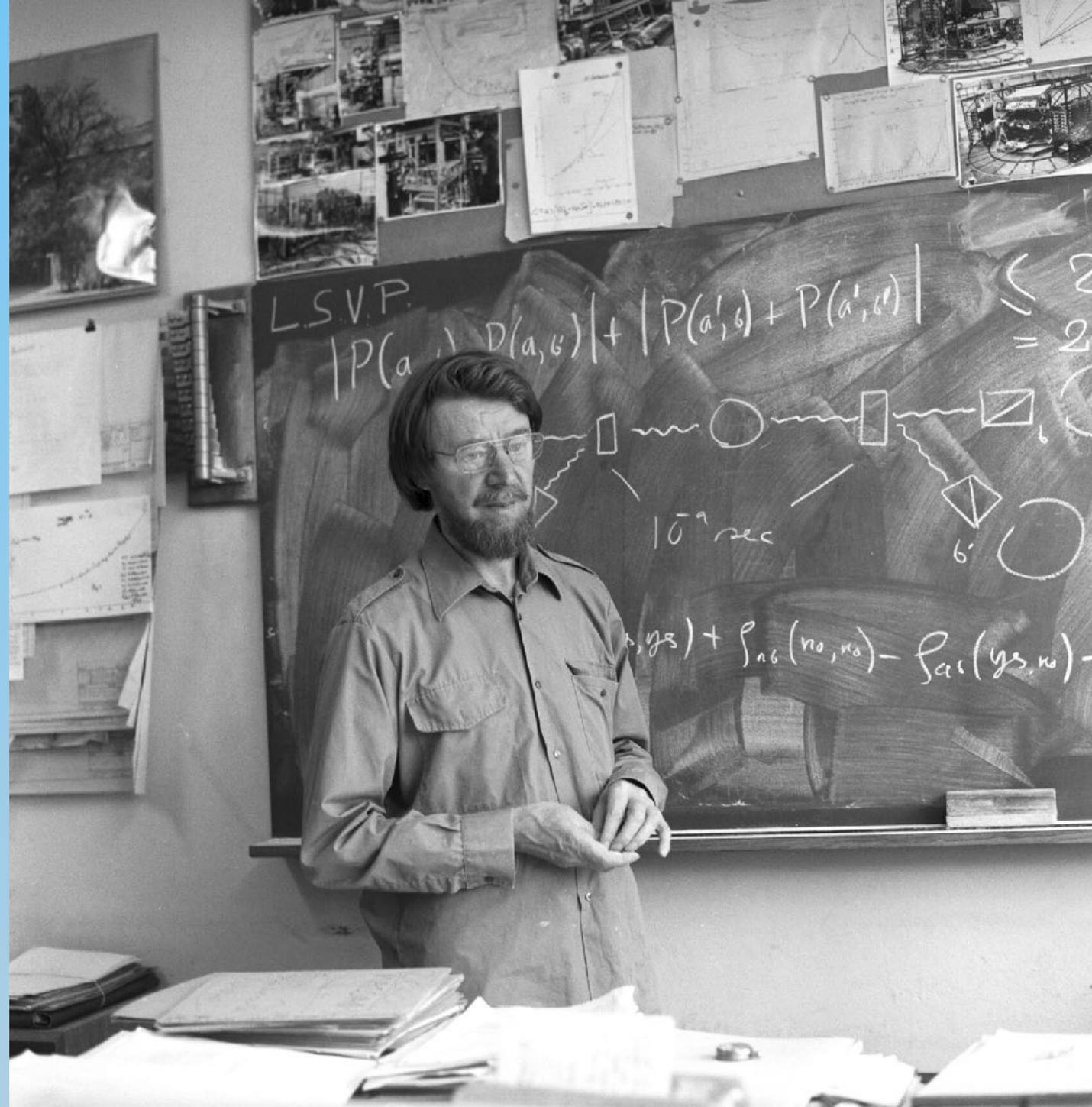
- A source emits two spin 1/2 atoms in opposite directions.
- Conservation of momentum dictates that the sum spin is zero, thus they must have opposite spins
- One atom goes through a Stern-Gerlach magnet (oriented in some direction)
- We know with probability 1 what the other (identically oriented) magnet will give.



Bell’s Theorem

Bell’s inequality

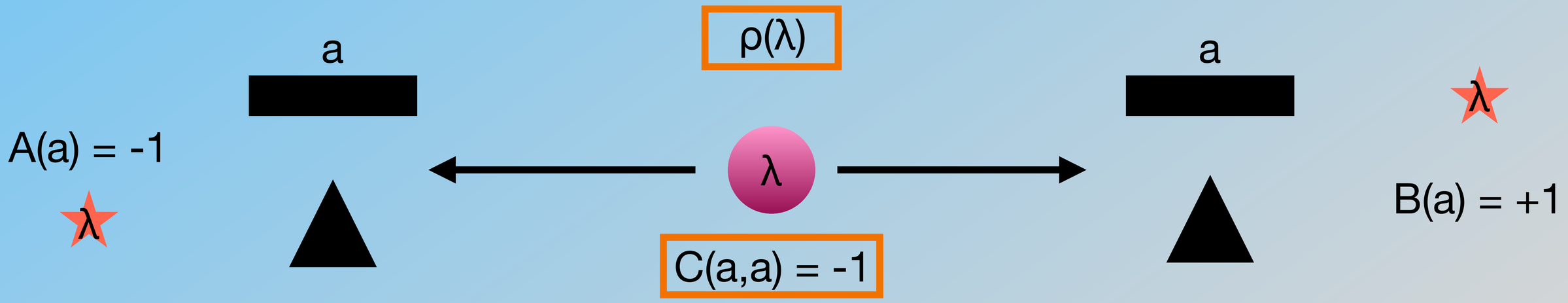
- In 1964 Bell published “On the Einstein Podolsky Rosen Paradox”
- Paper gave clear correlation conditions for local hidden variable models.
- Old problem of hidden variables could be tested for the first time.
- p 352: Bell was always…



Bell's Theorem

Setup

- a,b,c = unit vectors giving orientation of Stern Gerlach magnet
- C(a,b) = correlation of spins measured with orientations a, b
- λ = hidden variables
- ρ(λ) = pdf of hidden variables
- A(a,λ) = response of magnet A given a, λ. By construction A(·) ϵ {+1,-1}.



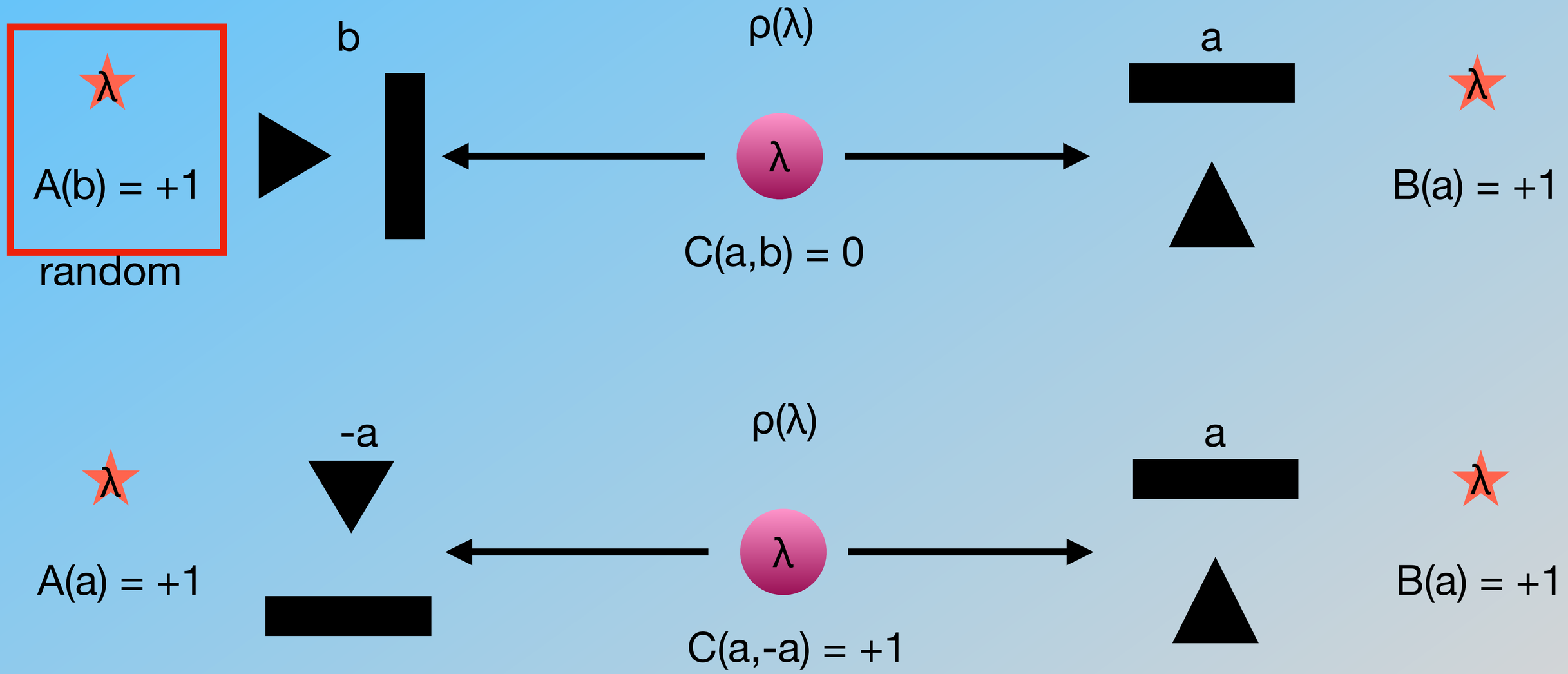
Bell’s Theorem

Setup

- λ = hidden variables — THEY ARE ENTIRELY GENERAL
  - “It is a matter of indifference in the following whether λ denotes a single variable or a set, or even a set of functions, and whether the variables are discrete or continuous.”
- “Note that Bell’s original paper assigned to λ only properties of the entangled pair. It is now generally assumed that λ may stand for a set of arbitrary physical variables including space and time coordinates… λ may also describe some properties of the measurement equipment (in addition to the magnet or polarizer orientation), such as dynamical effects arising from many-body interactions of the entangled pair with the constituent particles and fields of the measurement equipment. Bell agreed with this assumption in his later work.”
- In short, λ just stands for “mathematical ideas we have not yet had.”

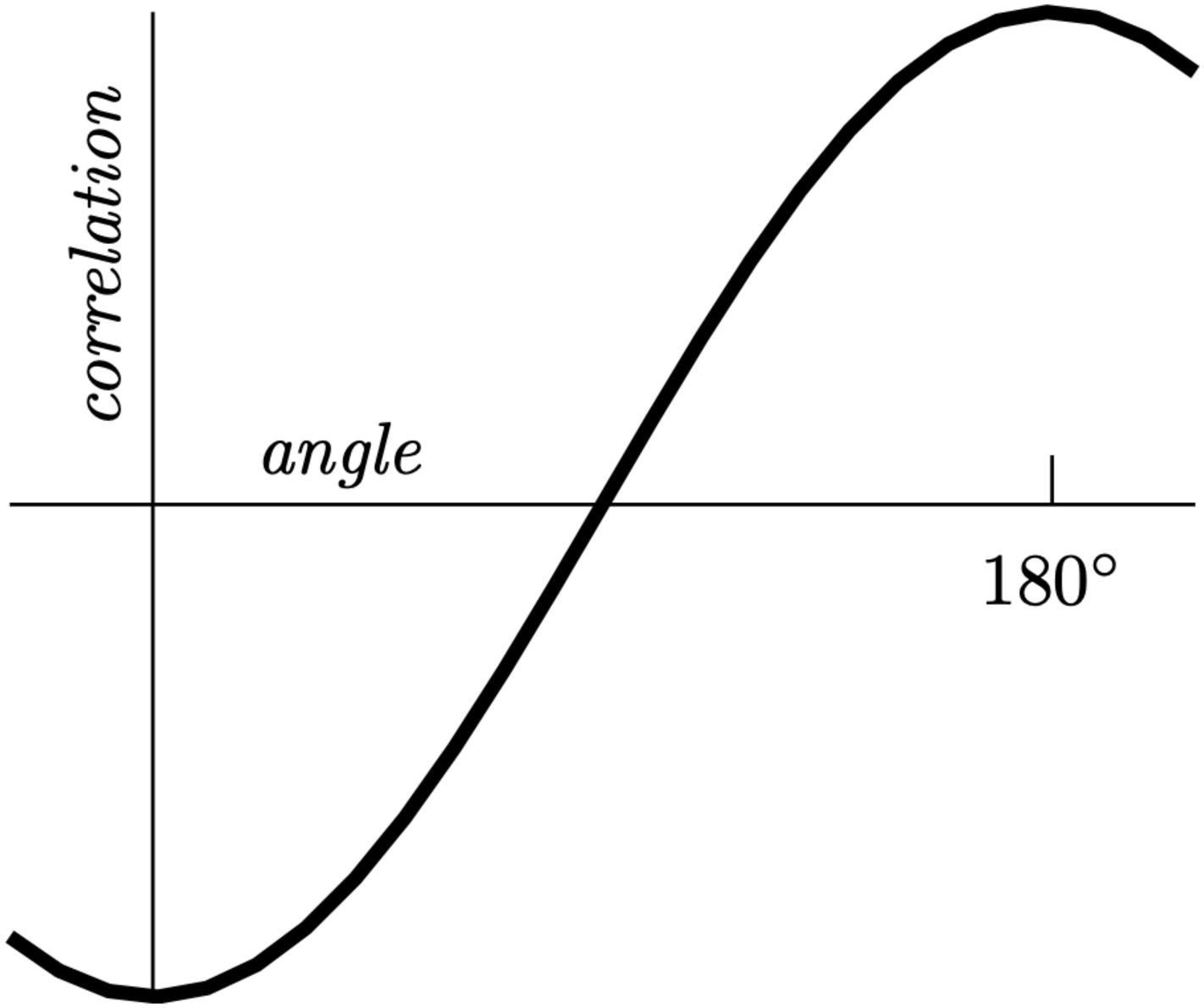
Bell's Theorem

Setup



Bell's Theorem

- C(a,b) = -a·b = -cos(θ)
- Take a moment and ask how scientists from ANY previous era would have approached these observations.
- p 352: Bell was always…



Bell’s Theorem

Three Assumptions

- Bell’s three assumptions:
  - Locality
  - Measurement independence (no-conspiracy)
  - Reality (counterfactual definiteness)

Bell's Theorem

Locality

- Einstein: "But on one supposition we should, in my opinion, absolutely hold fast: the real factual situation of the system S2 is independent of what is done with the system S1, which is spatially separated from the former" 1949

$$p(A, B|a, b, \lambda) = p(A|a, \lambda)p(B|b, \lambda)$$

- This is the very definition of statistical independence. The simplest kind of relationship is none at all: suppose we can split our random variables into two or more subsets that don't influence one another. Then these subsets are called independent of one another. We can represent independence by writing our overall probability as a product of two or more factors, where the factors have disjoint sets of arguments.

$$P(X_1, X_2) = P(X_1)P(X_2)$$

Bell's Theorem

Measurement Independence

- The hidden variables (in the atoms) are completely independent of the measurement angles

$$p(a, b|\lambda) = p(a, b)$$

- If this was not true, how we decide to measure depends on the causes of what we actually measure. E.g. I look at my watch because it is now 1:22, something in the universe caused it to be 1:22 AND caused me to check the time. If it were not 1:22, I would not have looked at the time.
- Denying this has been called "superdeterminism."
- "It is like a shill for the tobacco industry… when confronted with randomized experiments on mice… going on to say that the coin flips (or whatever) somehow always put the mice already disposed to get lung cancer into the experimental group and those not disposed into the control. This is completely and totally unscientific, and it is an embarrassment that any scientists would take such a claim seriously."—Tim Maudlin

Bell’s Theorem

Reality (Counterfactual Definiteness)

- A(a) has a definite value when we measure it, and IF we had decided to measure A(b) instead, that ALSO would have had a definite value.
- In other words, we can define functions.

Bell's Theorem

The inequality

$$|C(a,b) - C(a,c)| \leq 1 - C(b,c)$$

1. The inefficiencies of the counter, and so on, are essential. Quantum mechanics will fail in sufficiently critical experiments.
2. There are influences going faster than light, even if we cannot control them for practical telegraphy. Einstein's local causality fails, and we must live with this.
3. Einstein's local causality can survive. But apparently separate parts of the world become deeply entangled, and our apparent free will is entangled with them.
4. The whole analysis can be ignored. The lesson of quantum mechanics is not to look behind the predictions of the formalism. As for the correlations, well, that's quantum mechanics...

loopholes

locality

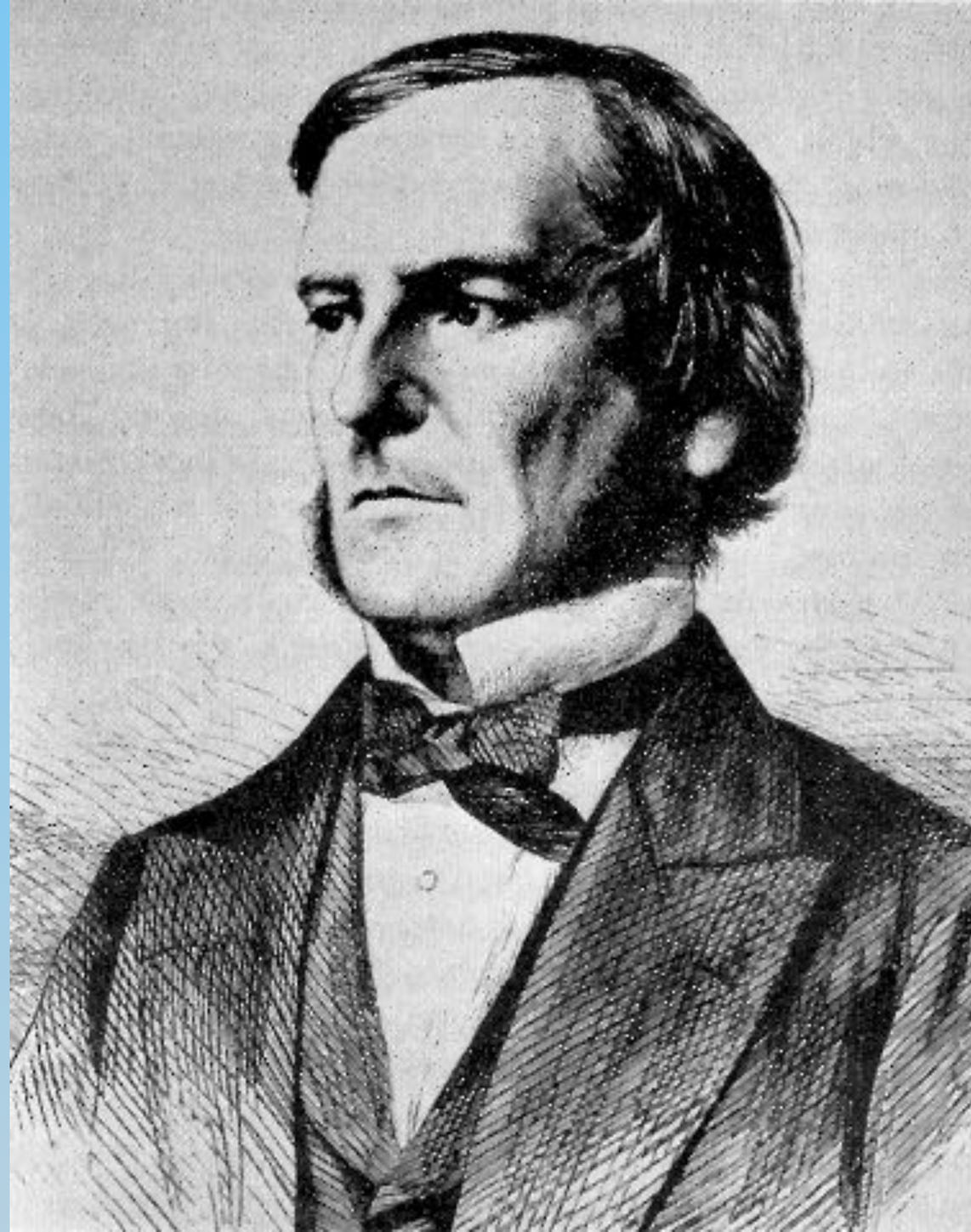
superdeterminism

there are no λ

Bell’s Theorem

The Fourth Assumption

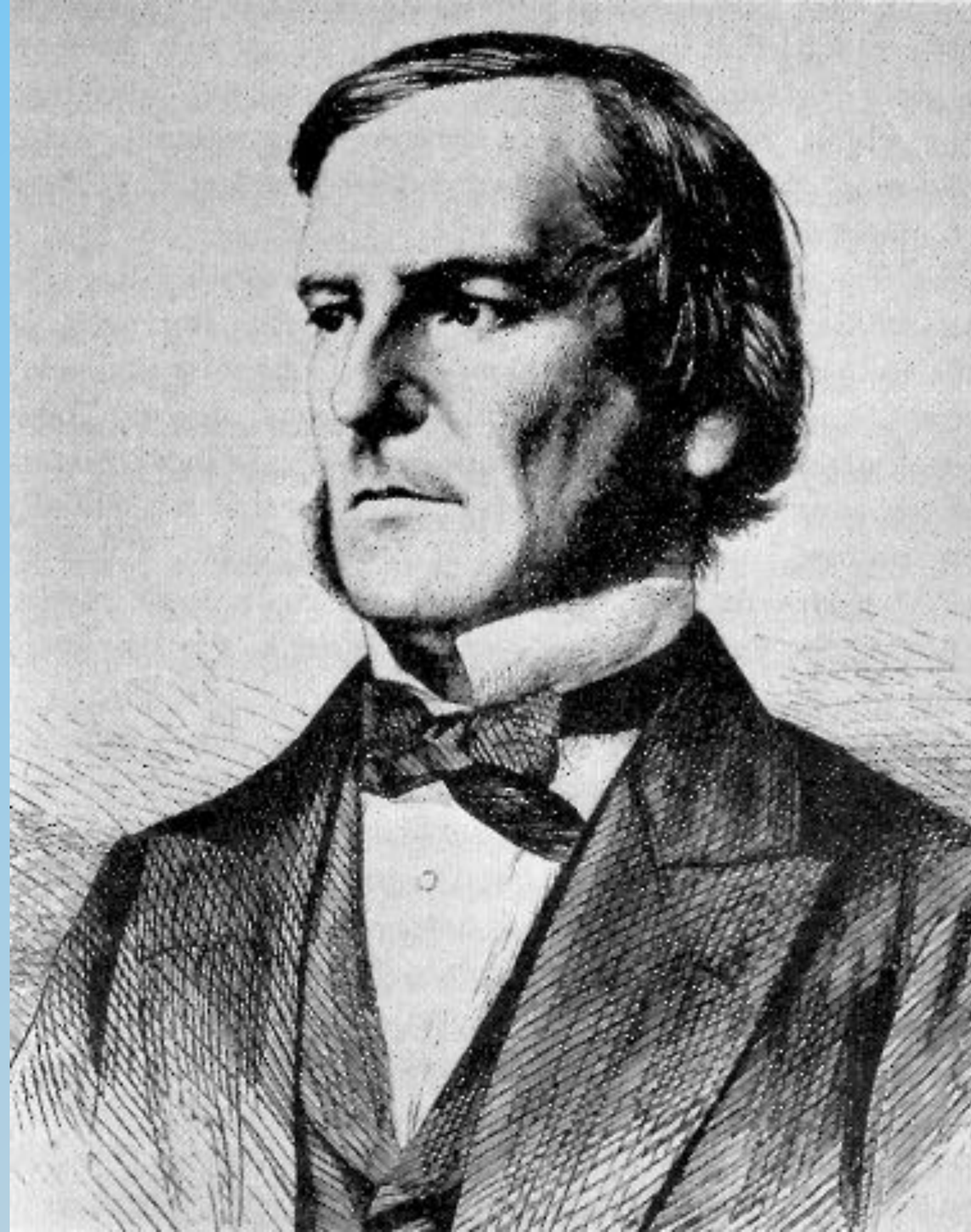
- In 1854 George Boole wrote *The Laws of Thought.*
- It contains the first appearance of “Bell’s Inequality”
- In 1989 this was pointed out by Itamar Pitowsky, in *From George Boole to John Bell - The Origins of Bell's Inequality*



Bell's Theorem

The Fourth Assumption

- "Bell type inequalities have a long history, beginning in mid 19th century. They have important applications in various branches of mathematics and mathematical physics: Combinatorial theory, probability theory, propositional logic, the theory of computational complexity, the Ising spin model and neural networks, and of course, the foundations of quantum mechanics."
- "it is interesting to note that Boole referred to the constraints he obtained as *conditions on possible experience*"



Bell's Theorem

The Fourth Assumption

XII. *On the Theory of Probabilities.*

By George Boole, *F.R.S., Professor of Mathematics in Queen's College, Cork.*

Received June 19,—Read June 19, 1862.

This paper has for its object the investigation of the general analytical conditions of a Method for the solution of Questions in the Theory of Probabilities, which was proposed by me in a work entitled "An Investigation of the Laws of Thought" (London, Walton and Maberly, 1854).

Problem. Given that the probability of the concurrence of the events x and y is p, of the events y and z, q, and of the events z and x, r. Required the conditions to which p, q, and r must be subject in order that the above data may be consistent with a possible experience.

Bell's Theorem

The Fourth Assumption

$$p \overline{\geq} q+r-1,\ q \overline{\geq} r+p-1,\ r \overline{\geq} p+q-1.$$

Such are the conditions of possible experience in the data.

Suppose, for instance, it was affirmed as a result of medical statistics that, in two-fifths of a number of cases of disease of a certain character, two symptoms x and y were observed; in two-thirds of the cases the symptoms y and z were observed; and in four-fifths of the cases the symptoms z and x were observed; so that, the number of cases observed being large, we might on a future outbreak of the disease consider the fractions $\frac{2}{5}$, $\frac{2}{3}$, and $\frac{4}{5}$ as the probabilities of recurrence of the particular combinations of the symptoms x, y, and z observed. The above formulæ would show that the evidence was contradictory. For, representing the respective fractions by p, q, and r, the condition $p \overline{\geq} q+r-1$ is not satisfied. (*Edinburgh Memoir.*)

Bell's Theorem

The Fourth Assumption

$$r \geq p + q - 1$$

$$\text{probability of concurrence} = \frac{1}{2}\text{correlation} + 1$$

$$2r - 1 \geq 2p + 2q - 2 - 1$$

$$C(a,c) \geq C(a,b) + C(b,c) - 1$$

$$C(a,c) - C(a,b) \geq C(b,c) - 1$$

$$C(a,b) - C(a,c) \leq 1 - C(b,c)$$

$$|C(a,b) - C(a,c)| \leq 1 - C(b,c)$$

repeat for

$p \geq r + q - 1$

to get

Bell's Theorem

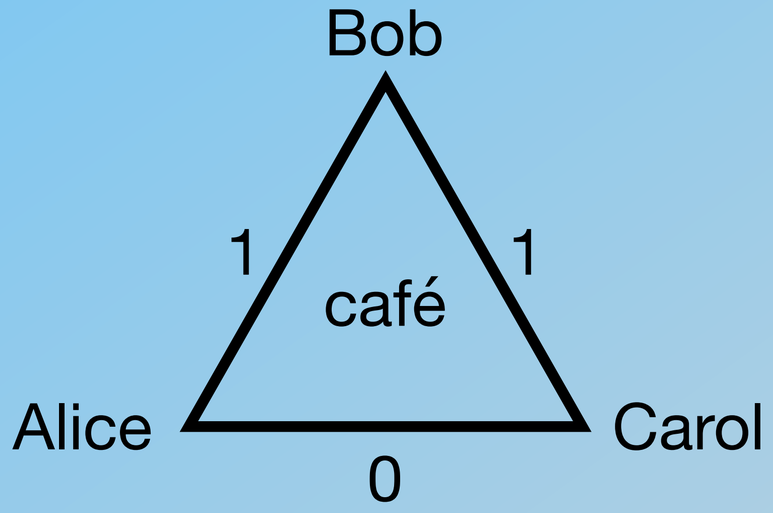
The Fourth Assumption

Other fallacies involve so-called *"experimental proofs of the Kochen-Specker (KS) theorem"*—because "how can you measure a [proof by] contradiction?" [20]; as well as *"experimental proofs of contextuality"*—what is actually measured are violations of Boole-Bell type inequalities *via* successive measurements of counterfactual, complementary observables that are not co-measurable [21]. Although contextuality might be *sufficient* to render

Bell's Theorem

The Fourth Assumption

- p 369-371
- p 374-377



$$P(\text{Alice café, Bob café}) = P(\text{Alice lab, Bob lab}) = 50\%$$

$$P(\text{Bob café, Carol café}) = P(\text{Bob lab, Carol lab}) = 50\%$$

$$P(\text{Alice café, Carol lab}) = P(\text{Alice lab, Carol café}) = 50\%$$

Bell's Theorem

Contextual Probability

entropy

MDPI

Article

Electron Spin Correlations: Probabilistic Description and Geometric Representation

Ana María Cetto

Bell's Theorem

Contextual Probability

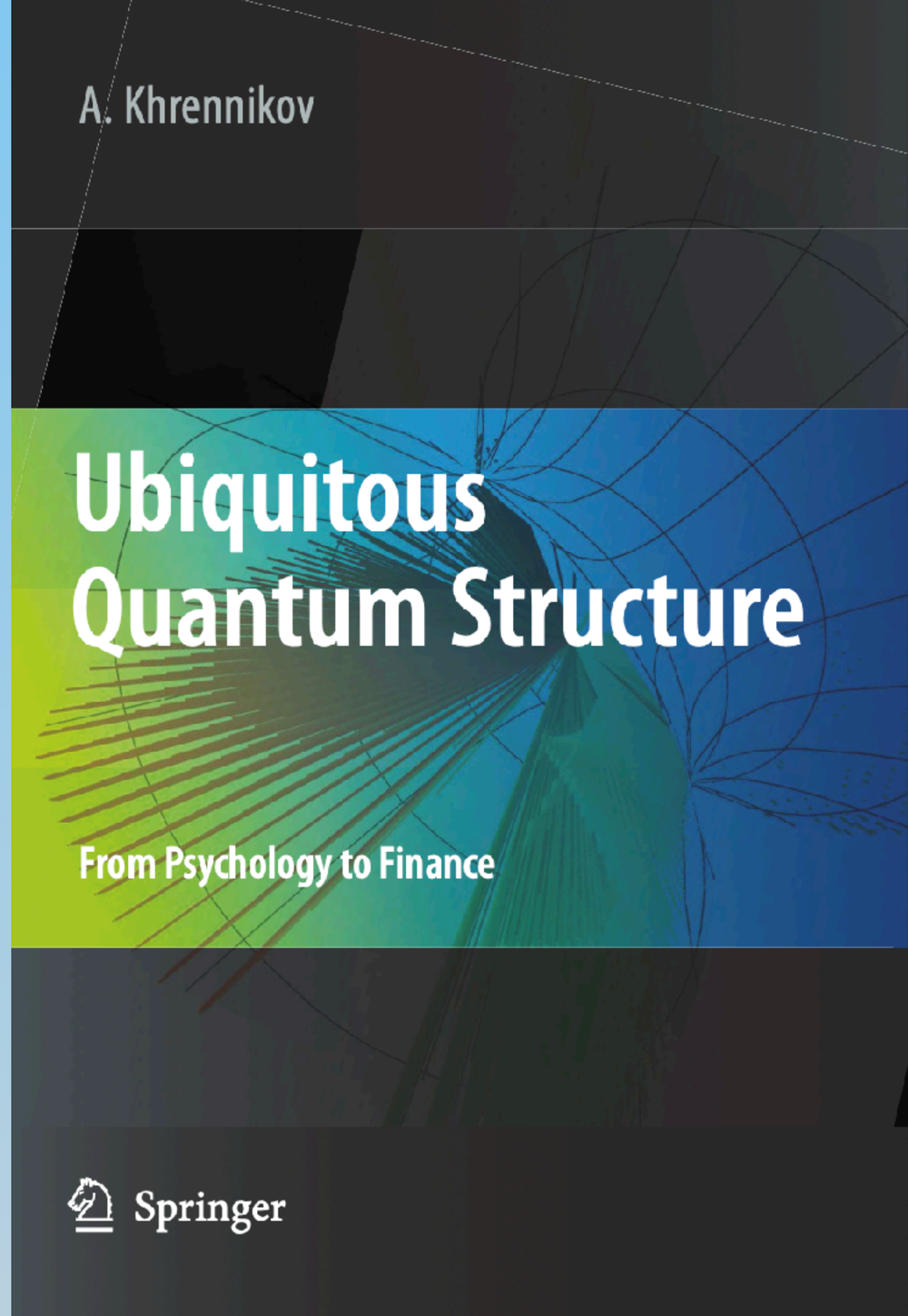
Consideration of the context dependence of the probability space partitioning is essential to arrive at a geometric representation of the proposed probability distribution function $\rho(\phi)$, whose argument ϕ varies at random within its integration range. This hidden-variable description is shown to reproduce the probabilistic features [4] and the quantum result for the one-electron spin correlation. An analagous procedure is shown to be applicable to the bipartite singlet spin case. That both cases can be dealt with following a similar approach is due to the use of conditional probabilities in calculating the respective correlations. Further to endowing the probabilities with a concrete meaning, the results obtained open the possibility of an understanding of the physics that underlies the quantum description. A proposal in this regard is advanced at the end of the paper in light of recent experimental evidence pointing to a finer dynamics of the spinning electron, which requires further investigation.

Bell's Theorem

Contextual Probability

- "The aim of this book is to demonstrate that *quantum-like* (QL) models, i.e., models based on the mathematical formalism of quantum mechanics (QM) and its generalizations, can be successfully applied to *cognitive science, psychology, genetics, the economy, finances, and game theory.*"

- quantum mechanics is just the first example of successful application of *non-Kolmogorovian probabilities*, the first step towards a *contextual probabilistic* description of natural, biological, psychological, social, economic or financial phenomena.



Bell's Theorem

- C(a,b) = -a·b = -cos(θ)
- p 389 seq.