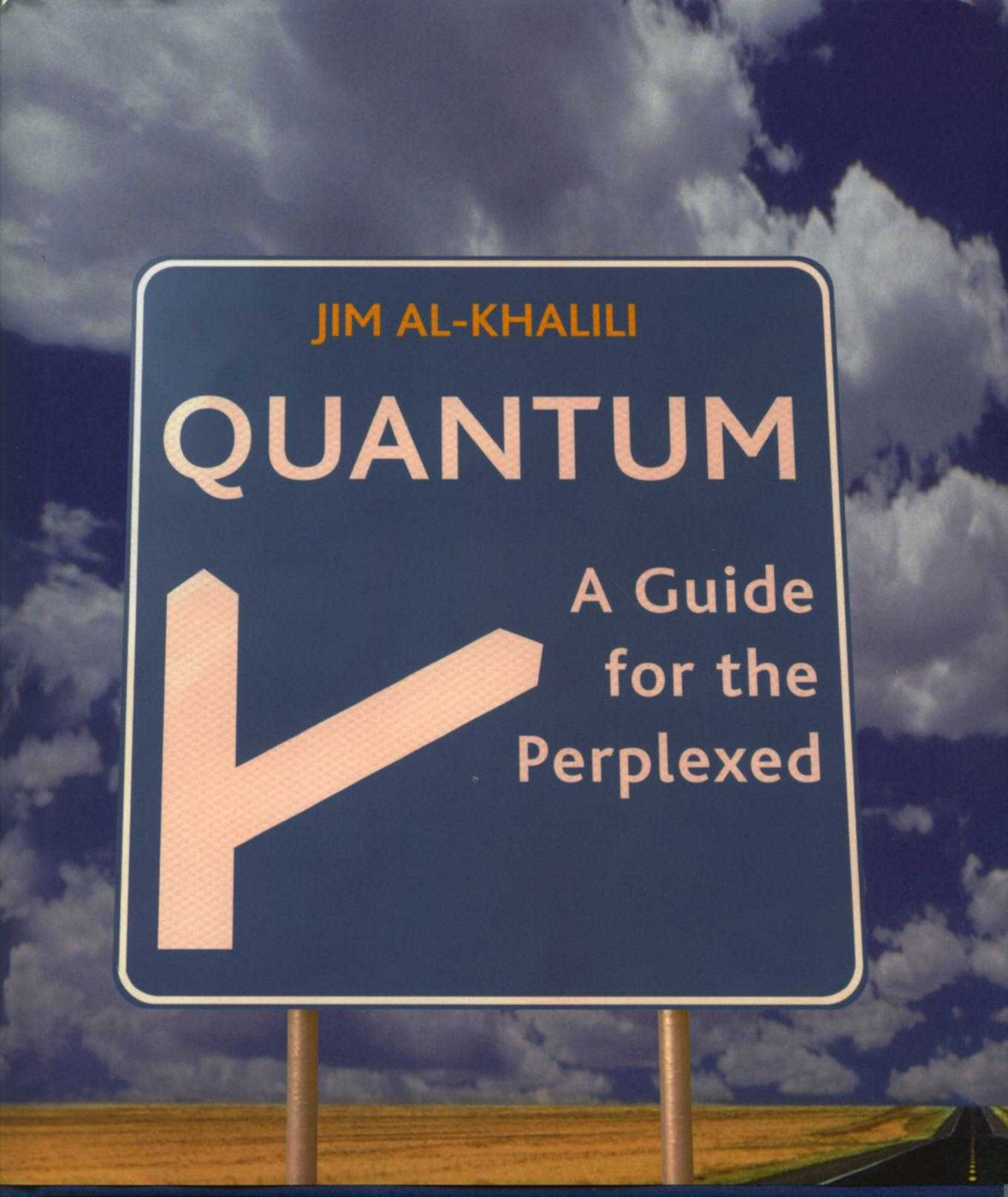
JIM AL-KHALILI
QUANTUM
A Guide
for the
Perplexed

This book is dedicated to my father, to whom I am indebted for, among many things, first telling me about some strange theory called quantum mechanics.

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No cats were harmed in the making of this book

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Buckyballs and the Dual-Slit Experiment

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We usually think of a physical body as a localized object while the notion of a wave is intimately linked to something extended and delocalized. Contrary to this common belief quantum physics claims that both, seemingly contradictory, notions can apply to one and the same object in one and the same experiment.

We have recently implemented such an experiment with large carbon molecules called buckyballs. These molecules, known as C_{60} and C_{70}, contain sixty or seventy carbon atoms each, arranged to form the smallest known replica of a soccer ball, with a diameter no bigger than one millionth of a millimetre. In spite of their small size these molecules are the most massive objects ever used to demonstrate the wave-like nature of matter to date.

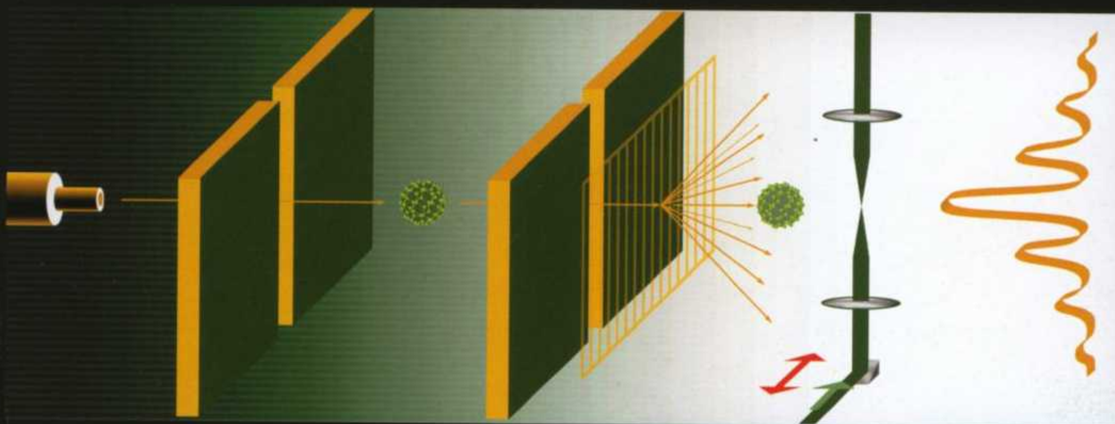
The experiment is set up as follows. The molecule source is a simple oven, filled with the carbon powder. The molecules can escape from a hole, like water vapour escaping from a hot kettle. They then fly through two collimating slits towards a laser detector with high resolution that can be shifted to record the spatial distribution of the molecular beam.

On the way towards the detector the molecules may encounter three different possibilities – either no obstacle at all, or a very narrow slit or a very fine grating, which is a membrane with several slits.

The molecular beam profile for the first, 'empty', case is a single narrow peak and is in complete agreement with our naïve expectation, assuming that each molecule can be regarded as a free-flying classical ball.

However, the first weirdness occurs in the second case: If we place a single, very narrow slit – 70 nanometres (millionths of a millimetre) wide – in between the source and the detector we find a profile on the screen that differs from the empty case. We notice a strong broadening – instead of the narrowing, which we would have expected if the molecules were just little soccer balls. This is a consequence of diffraction, a property of waves.

The situation becomes even stranger when we replace the narrow slit by a grating. This structure is now composed of several openings, slightly narrower (nominally 50 nanometres) than the first slit. The slits are regularly spaced (about 50 nanometres apart). If molecules were simple particles we would expect an increased signal everywhere on the screen. But – to the surprise of our common sense – we now find that there are positions where we hardly detect any molecules at all.



Opening two or more pathways in the wall, instead of only one, reduces the number of detected molecules at certain places. This is very counter-intuitive and can no longer be explained with the model of classical balls flying along well defined paths, but it is in perfect agreement with a model based on the wave-nature of single molecules. Here we give up on the concept of a 'trajectory' and allow the molecules to simultaneously explore an extended space, which is orders of magnitude larger than the molecule itself, resulting in quantum interference.

It is important to note that the clicks in the detector are well localized and that the location where an individual molecule arrives is absolutely random, as far as we can tell. But still, the weird wave-like pattern is built up as more and more molecules hit the detector.