Quantization and quantization

The discussion broadens to encompass "matter" in addition to "radiation", by examining what the term quantization means. Dr Murray discovers a novel and important method of distinguishing between science fact (physics) and abstraction (metaphysics).

I am in favour of realism in physical thinking, and against twentieth-century mysticism. The doctrine of the duality of light as currently taught to physics students – that light consists sometimes of waves and sometimes of particles or "quanta", even though its wave particle forms are incompatible and mutually exclusive – strikes me as mysticism of the most blatant kind. I have suggested resurrecting an alternative view, attributable to Einstein, that light "waves" as inferred experimentally are manifestations of systematic variations in space and time of the density of photons: that is to say particle-like entities carrying energy and momentum' and travelling at the speed of light. The proposal leads to simple explanations of many well-known phenomena of light, but one is not surprised to find it in sharp conflict with electromagnetic theory.

Whether or not this particular alternative to electromagnetics and the duality doctrine, which may be called the photon-waves concept, will stand up to meticulous scientific inquisition is not at this moment of very great consequence since other alternatives are to hand, although perhaps none has quite the same appeal of simplicity. The concept could be tested experimentally and it would be prudent to speculate no further until the suggested experiments have been performed. I propose now to leave the paradox of the duality of light and to refer to it only in the context of its effect on the remainder of modern physics – in particular in the context of the consequential and even more mystical postulate of the duality of matter.

From now on in this review the terms quantum theory, quantum mechanics, and quantization will appear frequently, so it would be convenient to begin by defining what they mean. Unfortunately that is not easy, because they mean different things to different people and sometimes – shades of duality! – they even mean different things to the same person at different times or even at the same time. We are about to enter territory where "double-think" is the rule rather than the exception, and my purpose is, so far as I am able, to hack a path of old-fashioned scientific realism through a mystical jungle of confusions, *non-sequiturs*, and straight logical impossibilities. There are at least three different current uses of the word quantization, and we shall be philosophically safer if we understand what each of them means, how they differ from each other, and why.

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The first "quantization" to see the light of print was probably the one connected with Planck's original quantum hypothesis. It can be discussed in terms of a famous thought-experiment that we shall return to later in another context. Visualize, if you please, a beam of light falling to a half-silvered mirror set at an oblique angle to the beam. Of the light which falls on the mirror, some is reflected and enters a detector which we may consider to be an ideal photoelectric cell; the rest passes through the mirror and continues straight on indefinitely, into deepest space beyond our ken. The question being asked is, *how much* of the light is reflected into the detector, and how much is transmitted away and for ever lost to us?

For so long as light was believed to consist of electro-magnetic waves in an ether fluid there was no problem here; there was no restriction on the relative heights (amplitudes) of the reflected and transmitted wave crests. The reflected wave could be increased and the transmitted wave could correspondingly be decreased by any amount desired; in particular, there was nothing to prevent an adjustment being as small as one chose to make it. In mathematical terms we say that the light intensity, being the square of wave amplitude, could be changed *continuously*. By way of contrast, if light energy is really packaged into quanta as the experimental evidence so clearly demands, then the smallest adjustment that can be made is when one quantum, which was otherwise to have been transmitted and lost, is now reflected (and therefore detected) instead. The smallest possible change is now finite – one quantum – and we say that such changes are mathematically *discontinuous*.

Now if the light beam is bright enough to be visible, so that millions of quanta are being detected every micro-second, the gain or loss of one quantum isn't going to make much practical difference: the change of intensity is still effectively continuous. That is no longer so however in cases where quanta are in short supply (as in very weak light or in the case of very energetic quanta such as gamma rays). In the ultimate case, if there is only one quantum present the question of whether it is reflected or transmitted is unequivocal: either it is reflected and detected or it isn't, 1 or 0, yes or no. This is quantization type one. It arises because light comes in the form of discrete particles or quanta and is *not* wavelike. There is nothing indeterminate or hazy about it; it must be one of the most precise processes we can possibly imagine.

We can, if we insist on doing so, muddy these clear waters with a fog of irrelevances: we can say, truthfully, that the outcome is in doubt *before the event*, because we cannot predict *before the event* whether that particular quantum will be reflected or transmitted by the mirror. From this it is usually argued, according to established physical doctrine, and I hold – utterly in error – that our inability to predict the outcome is proof that the mechanism of the reflection of light by the mirror is fundamentally "indeterminate". For the moment I will suggest two thoughts to ponder on this issue, one old and one new.

The older thought is that we cannot predict which way a particular quantum will go because we don't know about the conditions of its encounter with the mirror surface in sufficient detail; for instance, we don't know beforehand whether it will hit one of the silver atoms or pass between them. As we shall discover when we come to discuss Heisenberg's "indeterminacy principle", there are good, non-mystical reasons why we cannot predict whether or not it will hit a silver atom; but broadly speaking, and without yet defining too tightly what we mean by hitting and missing, it is reasonable to say that those quanta that hit will be reflected, and those that miss will pass through. There would seem to be a fairly obvious causal connection here between hitting and bouncing, or missing and penetrating. The mere fact that we humans cannot predict the outcome in a particular case – because we are unable to measure its initial conditions – does not imply that the reflection process at the mirror surface is imprecise or indeterminate in any way. How could it imply that?

The new thought I introduce (at any rate I believe it to be a new thought) is this: there is no indication anywhere in physics that Nature ever makes a prediction! The whole idea of prediction is foreign to Nature and introduced by Man. It is in the nature of living matter – at all levels – to build enzymes, protein-coats, nests, aqueducts and aeroplanes for its own convenience. It does this by decreasing entropy locally at the expense of its environment (eg. energy profligacy, pollution), without violating the second law of thermodynamics overall. The desire to make predictions as an essential element in the management of one's surroundings is seen to be merely one aspect of this characteristic of life. Decisions which follow are not necessarily rational, nor are consequent actions always "determinate".

In clear contrast to this, all the evidence of observational and experimental physics tells us that inanimate Nature, the Nature of the physicist, takes no account of the future or of the past but "lives only for the present". The outcome of a physical interaction would seem always to be the strictly causal result of the integration of the conservation laws (expressed in terms of physical forces) over the ever-changing total situation at time *now*. The futuristic concepts of "will", "purpose", "intent", and also "prediction", are non-physical attributes of living matter, and physical Nature is not concerned with them. In line with ordinary linguistic usage we may properly call concepts of this kind metaphysical – transcending physics. This is the sense in which I shall use the word metaphysics from now on.

Once we have understood that prediction, the greatest aim of all science, does not in fact form part of the working of the kind of Nature with which physical science is concerned, a major source of confusion is identified and dealt with. It becomes easier to put our inability to make certain kinds of prediction, especially in the microphysical domain, into its proper perspective. Nature can get on very well without us! Overwhelming experimental evidence supports the view that the principal denizens of this smallest domain, atoms and molecules, protons and neutrons, electrons and light quanta (or photons), are quantized in the sense used originally by Planck: they are discrete, physical entities having real, free-standing existence independently of each other and of any observer, human or deputy. Moreover, the fact that an electron is so light that we cannot measure exactly where it is without disturbing it does not mean that the electron's location is not precisely defined; nor does it require that there must be anything indeterminate about the electron itself as a particle, or about its interactions with other particles. A lot of nonsense has been written about such things, by people who should have known better.

I have been labouring these issues because conventional doctrine takes the diametrically opposite view of every one of them. We shall discover the reasons for this when we come to review the origins of the quantum-mechanical theory. The point we have picked up here is that the word 'determinate" is not synonymous with "predictable by mankind". The arrogant assumption that it is has given rise to much philosophical trouble in physics. Let us be clear about our own humble position in the scheme of things: *we* may not be able to predict the reflection or transmission of any particular photon, but there is every reason to suppose that the behaviour of that photon is determined, and precisely determined, by causality and the conservation laws. Certainly there is no experimental evidence to suggest that it is not, whatever current doctrine, dogma, or "theory" may say.

So there we are. We have examined one meaning of the word quantization and found that it has to do with the essential granularity of microphysics. Electrons and photons behave like very tiny particles. Either you detect them or you don't: you never detect half an electron or three-quarters of a photon. That is all there is to it. Whether or not one can predict the outcome of a microphysical event is a completely different ball-game; the limiting accuracy of our predictions has nothing to do with whether light consists of particles or of waves. There really is nothing mystical here, and we need not be confused about it unless we choose to be.

The second historical meaning of quantization arose out of a famous piece of fundamental work by Niels Bohr. Visiting Manchester as a young exchange student, he came across the experiments and reasoning that led to Rutherford's atomic model – negatively-charged electrons circulating perpetually like tiny planets around a heavy, positively-charged nucleus. He also found that Rutherford's very clever and competent research team were stuck on two points which threatened to wreck their pretty model. There seemed to be no reason why the electrons should circulate in those particular orbits whose frequencies corresponded to the observed spectra of the light emitted by the atoms; and there seemed to be nothing to prevent an atomic system from running down like an unwound clock, as the electrons radiated their orbital energy away into space. The last-mentioned effect was predicted by the all-powerful electromagnetic theory on the grounds that a circulating electron is an "accelerated point charge", which according to that theory must radiate continuously. (Between ourselves, you may recall, we have grounds for believing that electromagnetic theory may have been wrong on that point, but that wasn't suspected in 1912 and we needn't go into its consequences until we are ready.)

Bohr was unusually well-placed to tackle these problems because he had recently made an advanced study of Planck's still-new quantum hypothesis, which said that (contrary to another statement of electromagnetic theory) the evidence of experiment is that light energy is not radiated continuously but in discrete packages. Bohr applied this as-yet unexplained hypothesis to the Rutherford atom, but in so doing he also applied a completely new and additional postulate of his own. "Light energy is quantized into packages; how would it be if all energy were quantized into packages?" he generalized.

As a first shot one could postulate that the energies of electrons in atomic orbits were quantized in this way, by assuming that only certain discrete energy-levels or states were permitted inside the atom. Inevitably, this postulate enabled the atomic spectra to be explained in principle; but the explanation was a brute-force one, *ad hoc* and untidy, since the packages of energy turned out to be of differing, awkward sizes. Bohr then examined the other properties of these permitted orbits and found that their angular momenta progressed evenly, in equal steps; always *and for all atoms* the step size was the same curious quantity $h/2\pi$. (For the specialist I will remark that this h is Planck's constant, as derived in his quantum hypothesis, while the 2π converts the dimensions of h from those of "action" – erg-seconds – to those of anular momentum). Atomic spectra could now be calculated from the Rutherford atomic model on the basis that the angular momenta of the planetary electrons, rather than their orbital energies, were quantized into systematic, discrete values. No explanation was offered by Bohr as to why angular momentum should be quantized: the assumption was to be justified by its spectacular results.

There can be no disputing the brilliance of this piece of work by Bohr in the year 1913, and what I next have to say must not be construed as detracting from it. That is not my intention. I wish merely to pinpoint what Bohr actually did.

Planck's quantization (type one) we have already found to mean simply that light

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Interpretation of the "quantum" concepts

The mystical concept of duality in light was paralleled in 1925 by the even more mystical postulate of a particle/wave duality in matter. In this area confusion and "double-think" now reign supreme, and clarification is long overdue. Three completely different meanings are ascribed impartially to the single word "quantization". In its first sense (Planck) it refers to the natural consequences of the fact that the physical world is granular on the microphysical scale: both matter and radiation behave as if they were composed of independent, indivisible particles. Quantization in this sense means simply that a photon is either reflected or not reflected at a mirror surface – yes or no, definitely and without half-measures. The question of whether or not the outcome of the encounter can be predicted before the event is not related to quantization. That question has two important philosophical branches: (a) accurate prediction depends on detailed knowledge of the experimental conditions, and (b) prediction is never indulged in by inanimate Nature, but on the contrary is an activity characteristic of *living matter* only. This much-ignored truth enables one to distinguish between physics and metaphysics, and also between inanimate determinism and predictability; failure to maintain such distinction was the first serious philosophical error of modern physics.

The second historical meaning of "quantization" referred to the postulate (Bohr, 1913) that mechanical working-parameters such as energy and momentum may also be in some way granular, and that they may be exchanged between physical entities only in steps of discrete size. An attempt to rationalise this postulate by attributing quantization to the action of "matter-waves" proved abortive, but by convention that failure is not normally admitted or taught. The third common meaning of the word may be taken to refer to a mystical mechanism offered by way of "explanation" of any phenomenon by the wave theory of matter.

energy comes in packages which have all the experimental characteristics to be expected of discrete particles; on the scale of atoms and photons the physical world is granular in its nature. Bohr's quantization (type two) is totally different: it does not have to do with microphysical entities as such, either as to their size or their particulate form, but refers to the apparent restriction of a mechanical working parameter, in this case angular momentum, to certain universally-discrete values. One quantization acknowledges that microphysical entities are discrete, self-contained and indivisible; the other postulates that the laws of mechanics are essentially discontinuous in their operation. The only connection between these two completely different meanings of the word quantization is that thinking in terms of the one led Bohr's imaginative mind toward the concept of the other.

In retrospect Bohr's proposal was far more earth-shaking than Planck's, because while Planck's could be accepted by the overthrow of a theory, painful though that might be for the theory's supporters, Bohr's has never been explained. The conclusion was drawn generally, and I shall suggest prematurely, that ordinary mechanics had failed and that a new quantum mechanics in which energy, momentum, and angular momentum were in some mysterious way quantized must take its place. How else could the orbital electrons in the Rutherford atom be prevented from eradiating away their energy and coalescing with the nucleus? (Might there not be an alternative explanation?).

As I have said, no satisfactory explanation of Bohr's quantization has ever been forthcoming. Current doctrine adjures one to accept the outcome without explanation, on the grounds that "for fundamental reasons" it cannot be explained.

In the microphysical domain of atoms and electrons we physicists are to deal henceforth in miracles: for a miracle is a physical occurrence for which we can offer no physical explanation. Inventing "matter-waves" in an attempt to provide a rationale was an abject failure, but it led to a third common meaning of the word quantization, unconnected with the other two; we may define it as "A panacea which purports to explain any microphysical phenomenon, indiscriminately, in terms of the mystical tenets of the wave theory of matter". The subornment of physical thinking during the 1930's to the beliefs of the adherents of this theory is the final incredible tale I have to tell, but first I shall have to describe what the theory is about and explain where it came unstuck, and why. That in itself makes a fascinating story.

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Architecture of an electronic book

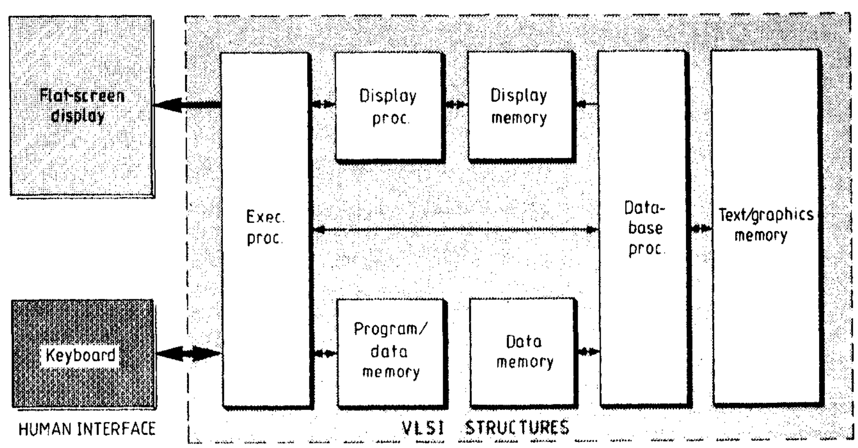
Rapidly increasing paper cost and advances in semiconductor and software technologies are prompting practical alternatives to the wood, glue and dye-based objects we know as books. Books intended to be read serially can conceivably be stored in a central bank and the information in them disseminated through networks similar to the ones currently being used as up-to-the-minute newspapers. But data manipulation necessary for electronic reference books, educational text books and technical manuals may require a different approach, mainly due to the need to search for information within them and because of their often specialised nature.

According to a recent proposal,* such books would be contained in plug-in roms and read on a flat-screen display. Perhaps anticipating the question, "Why not use an optical disc?", its authors remind us of the recent implementation of a 4Mbit wafer-scale rom which could be ready for manufacture in the mid-1980's.

"Current state-of-the-art flat-screen display technology suggests that it will be possible to house the display, keyboard, system-processor chips and a substantial number of rom structures each containing text and graphics for an entire book will fit into a package approximately the size of a conventional book," but the authors don't speculate on a possible introduction date.

Apart from saving trees, the book envisaged will also provide an efficient means of accessing information and make searching for concepts embedded in the text possible. In search mode, the processor thumbs the pages and presents the desired information either page by page or as page numbers with or without an extract of text from the page concerned.

Word-based encoding techniques give a factor of between three and five reduction in the amount of memory required over character-based encoding and straight-line approximation methods used allow engineering drawings and text-book illustrations to take up the same amount of memory as text, page-for-page. Roms of the type envisaged that lend themselves to storing high-resolution pictures are not expected to be available in the 1980's but the optical disc is suggested as a possible alternative.



Architecture of an electronic book, J. M. Murray & K. J. Klingenstein, IEEE Transactions on Industrial Electronics, vol. IE-29, Feb. 1982, pp.82-91.