A Heretic's Guide to Modern Physics

The limitation of indeterminacy

Knowing the difference between physics and metaphysics, likewise between "matter-waves" and probability theory, one can begin to understand where modern physics went wrong. Two well-known Copenhagen doctrines can then be taken apart: in consequence the law of causation can be restored to its rightful, paramount place in natural philosophy.

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I have drawn attention to the two principal confusions of thought which were allowed, or perhaps even encouraged, to enter physical science during the decade 1925 to 1935 and which have caused untold philosophical chaos ever since. These were: the indiscriminate juxtaposition or equation of physical entities, such as electrons and mechanical momentum, together with metaphysical entities such as probability and knowledge; and the failure to reject the wave theory of matter when it had been disproved (on both experimental and logical grounds), and to distinguish between its concepts and those of the legitimate statistical quantum mechanics. Even the popular name for the last-mentioned, "wave-mechanics", which derives from its conceptual origin under Schrödinger but is no longer relevant, contributes to the perpetuation of the muddle; a first-rate example of confusion is to be found in the frequently-used expression "probability waves".

Lest it should be thought that these confusions have been innocuous in their effects I will instance a famous statement by a member of the Copenhagen School which provides a vignette of both of them. The date of presentation was 1933, the place Chicago, the reporter Alfred Landé, and the speaker on this occasion Werner Heisenberg. He was referring to the partial reflection of light by a half-silvered mirror, in a thought-experiment that we have already considered in the contexts of quantisation and determinacy. His words were as follows:

> "There is, then, a definite probability of finding the photon either in the one or the other part of the divided ψ-wave packet. Now, if an experiment finds the photon in the reflected part, say, then the probability of finding it in the other part immediately becomes zero. The experiment at the position of the reflected part thus exerts a kind of action, a 'reduction of the wave packet', at the distant point occupied by the transmitted part. And one sees that this action is propagated with a velocity greater than that of light".

Feeling the draught, perhaps, he then went on to say,

> ". . . This 'action' can never be used for the transmission of signals".

By all accounts Heisenberg made this statement with a completely straight face and believed in what he was saying. It is manifestly nonsense, but for that very reason it may be difficult to make a rational reply to it. The argument that light waves are electromagnetic waves which carry energy and therefore cannot collapse faster than the velocity of light is not quite sufficient because Heisenberg has dodged it by referring to "ψ-waves". He is, however, proposing that *something* associated with the photon must collapse in this way; as Professor Frisch said in a passage that I quoted earlier,

> ". . . It would seem that something does travel along both paths in the interferometer even when only one photon is admitted; but what is it?"

Clearly we are right at the centre of the duality paradox.

The understanding that we have been able to build up of the dualistic machinations of Copenhagen will now stand us in very good stead for dealing with Professor Heisenberg's curious proposal. The ψ-waves that he is playing with are not real waves but metaphysical waves. They do not have to comply with the laws of physics. Like Castles in Spain, he can give them any properties he wishes. If those properties should make his equally metaphysical ψ-function provide a reasonably accurate statistical analogue of how real photons behave, that is all to the good, but his ψ-waves need not otherwise relate to the physical world and indeed for reasons that we have discussed it is clear that they must remain always "unobservable". They are subjective, mathematical abstractions. The photon, on the other hand, is a physical entity which is indivisible and which travels strictly at the speed of light. It goes one way or the other at the mirror surface, but not both; there is no question of a transmitted part of the photon collapsing when a reflected part is detected. The photon's existence is objectively real. So where is the paradox?

The rationale for Heisenberg's statement is that the intensity of his ψ-waves represents *the precision of his knowledge* of the past, present, and future location of this particular photon. (You will note that both "precision" and "knowledge" are metaphysical quantities, appropriately described by ψ-waves). When his knowledge becomes sure – 100% certain because he has detected the photon – the probability that it may be elsewhere instantly becomes zero, as he says. This has nothing to do with the photon, but only with his knowledge; it would be quite wrong to assume, as the Copenhagen School assumed and declared as doctrine on the basis of extensions of this argument and others, that the observer's knowledge or even the observer himself had any influence on the physical, mechanical process of detecting the photon. Indeed, neither the photon nor the rest of the apparatus cares two pence whether an observer is present or not. We now see that the metaphysical doctrine of the relevance of the observer was just another Copenhagen fallacy.

Before leaving this topic let me mention a point which was first picked up by Sir Karl Popper, who has tended to specialise in this sort of thing. Even his ψ-wave packet does not in fact collapse as Heisenberg says it does. The distribution of ψ-wave intensity as a probability density – the probability of finding a photon here or there – does not change when any one photon is detected. It is to be identified as a prediction, the probability of detecting "any" photon as estimated before the event; for after the event the probability of a contrary result is a meaningless concept. And however many times you may have tossed a coin, the probability of obtaining heads or tails on the next toss remains always the same, 50/50 . . .

Thus Heisenberg's celebrated puzzle of the "reduction of a wave-packet" turns out not to have been a puzzle after all. It was a man-made nonsense consisting of one false concept and two logical errors held together by two major confusions concerning, respectively, the mixing of matter-waves with probability theory and the mixing of metaphysics with physics. It was also unnecessary. We can see how it came about, but as physicists we have no cause to be proud of it.

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I am going to conclude my exposition by analysing one more example of twentieth-century mysticism in the same way. The great Principle of Indeterminacy was enunciated by Heisenberg in 1927, and its profound philosophical message has dominated human thinking ever since. Like so many concepts of modern physics it is partly true. My purpose now is to examine the limits of its applicability and truth.

In its legitimate form the Principle of Indeterminacy (or Uncertainty) has to do with making measurements. For a host of reasons, all of which in the end boil down to the desire to make predictions in order to better manage our surroundings, we are interested in the positions and motions of things. We measure the position and motion of an oncoming motor-car by eye when we are deciding whether or not to cross the road; for more precise measurements we make use of various instruments such as rulers, gauges and graticules. In the ultimate of fineness of measurement our measuring instrument may consist of one photon or one electron which we aim carefully toward the target object whose location we wish to know; the electron or photon will be reflected (or bounce) on contact, and its reflection will tell us where the object was. Microphysical Nature being granular or "quantized", this represents the most delicate measurement that we can ever hope to make.

It was Heisenberg who pointed out, correctly, that this process doesn't provide a measurement of where the object is, but of where it *was* at the instant of making the measurement. The measuring process itself must disturb the object being measured, to an extent that depends on how massive the object is. Projecting one photon of visible light at an elephant, for example, wouldn't shift the elephant very far, but if that same photon were to hit an isolated electron it would set it in motion at a speed of several hundred miles per second. (This is the Compton effect discussed earlier). If you were to use a less massive photon – that is to say, conventionally, a quantum of light of lower "frequency" or longer "wavelength" – you wouldn't disturb the target electron so much but you wouldn't get such a precisely-defined reflection from it either. You can't have it both ways.

Heisenberg condensed these ideas into what was to become one of the most famous Principles of physics. (For those who don't mind equations, I am referring now to $\Delta p \,.\, \Delta x \approx h$). Stated in words, it says that there is a natural limit to the accuracy (Δ) with which physical quantities can be *measured*. The position and momentum of any particle as measured are in a sense complementary. We can in principle devise an experiment to measure either position (x) or momentum (p) as accurately as we wish, but if we try to measure both simultaneously we come up against this natural limit. We cannot measure, and therefore cannot know, both the location and the subsequent velocity of an individual electron with greater accuracy than is indicated by Heisenberg's formula. No evidence has yet been found to suggest that his formula when interpreted in this way is not always and exactly true.

Now it must follow as the night the day that *if* we cannot measure the position and velocity of an electron precisely at the beginning of an experiment or during it, *then* we cannot predict with precision where that electron will be at the end of the experiment. The Principle of the indeterminacy of measurement must therefore lead directly to a corollary Principle of the limitation of prediction. This realisation came as an unwelcome shock to the physics of the 1930s and also, when news of it leaked out, to philosophy in general; for physical science had come to extol its ability to make precise predictions above all other virtues, while human vanity was unwilling to accept that there was anything that human technology ultimately could not do. Faced with this crisis of confidence it was perhaps inevitable that certain spirits should cast about in the hope of finding an escape clause.

We shall examine the defensive antics and flights of fancy of those folk in the next article, but before doing so it will be well to establish how far the *experimentally-verified* aspects of the indeterminacy principle can carry us. Suppose that a fundamental particle (an electron, say) is initially at point A at time zero and travelling at velocity v. According to our best possible measurements we know only that it is within, say, one micrometre of A at that instant and travelling subsequently at a velocity within, say, 100 metres per second of v. From this knowledge we can predict that the electron will in due course pass within one centimetre of a second point, B. The quantum mechanics as a mathematical tool will perform that prediction for us beautifully – there is nothing mystical about it or its calculations, which rely on the conservation laws. But we should note that it is not the position of the electron which is uncertain; it is *we* who are uncertain about its position. The electron itself travels from point A (exactly) to point B (exactly) along a track AB which is precisely determined. It is *our knowledge* of that track, not the track itself, that is imprecise; and it is *the imprecision of our knowledge*, not the physical body itself, that is transferred from the vicinity of point A to the vicinity of point B by the so-called "operators" – metaphysical operators – of the statistical quantum mechanics.

Now what I have just said constitutes a new interpretation of the function of the quantum mechanics or "wave mechanics", and it is controversial. It is also very dangerously heretical, because anyone who accepts it must eventually refute the Copenhagen dogma. I should therefore amplify it a little. Even Heisenberg, under pressure, admitted that his indeterminacy principle did not apply to retrospective measurements. By observing the same electron on two occasions very far apart in time and space, we can determine where that electron was at the time of the first measurement and how fast it was then moving, and we can in principle determine *both* those quantities after the event *to any accuracy we please*. I believe that to be the most important single point I have to make in all these discourses; for Heisenberg, hedging hard, claimed vehemently that such retrospective determinations, although valid, were irrelevant to science

Catastrophic misconceptions

A fine example of the effect on physics of man-made confusions is afforded by Heisenberg's famous proposal of the "reduction of a wave-packet". On the basis of physical arguments already generated it is possible to refute this proposal on three counts and to resolve it as a paradox. Similar treatment may be extended to the great Principle of Indeterminacy. It is readily argued that as applied to current measurements and forward predictions the Principle is almost certainly true. However, it is not true in the case of retrospective determinations, and it follows that, contrary to the generally-accepted Copenhagen doctrine, the behaviour of every microphysical entity is determinate and complies with the conservation laws. This is equivalent to the statement that the law of causality is obeyed universally in inanimate Nature, not only statistically but by individual micro-objects. Such a view is philosophically consistent with the laws of conservation. It is likely that the opposing (Copenhagen) doctrine, now widely held, arose from the 1930s confusion of inanimate physics, always determinate, with animate metaphysics, not necessarily determinate or rational.

(which he declared should be concerned only with prediction), whereas you and I will discern instead that they are highly relevant. We will recognise that our ability to calculate precisely the earlier position and momentum of an electron on the basis of later knowledge constitutes philosophical proof that the electron's behaviour during the interval was determinate. During that particular but arbitrary interval it must have obeyed the law of causality: and if then, always. The reason why this new argument is especially important, although one might have thought it obvious, is that the most celebrated doctrine of Copenhagen physics categorically asserts the opposite – that microphysical particles do *not* obey the causality law as individuals, but only "on average", in a statistical manner.

Thus the vital limitation or restriction which I now suggest must attach to the great Principle of Indeterminacy is that it may deal legitimately with the indeterminacy of measurement and prediction but may not, *repeat* not, express or imply any mystical indeterminacy of Nature. Despite general belief and conventional doctrine there is not, and never has been, any experimental evidence in support of the established idea that its operations are not bearings" and that its operations are not precisely determined. How that gross error came to be made will be reviewed in the next article, together with some examples of its catastrophic effects; in the meantime I shall ask the printer to set this statement out by itself, so that there can be no mistake about what I am saying:–

The law of causality is obeyed throughout inanimate nature

I cannot prove that statement. No scientific law can be proved, but its strength lies in the fact that no record exists of its ever having been broken. Specious Copenhagen "quantum" arguments notwithstanding, I can only re-assert that there is no experimental evidence against causality. Evidence in its favour surrounds us at every turn, because the law is itself a paraphrase of the great conservation laws of energy and momentum whose universal applicability is generally accepted. Therefore one cannot in logic acknowlege conservation while at the same time denying causality; that is what was so very odd about the 1930s doctrine that nature is indeterminate.

Almost certainly the confusion arose out of the failure to distinguish between physics and metaphysics, the science of the mind. There is plenty of evidence that *decisions* (made by living creatures)* are not always necessarily rational. That fact alone is sufficient to prevent a "Laplacian being" – or anyone else – from making an ultimately precise prediction of the future of the universe. Free will does, indirectly, modify the course of events, as human beings are fully aware; determinism applies only to inanimate, physical interactions. There is room in God's world for both vitalists and mechanists! But here for our sins we must stick with inanimate nature.

I said earlier, in connection with the reflection of photons by the half-silvered mirror, that the word determinate is not synonymous with "predictable by mankind", and went on to say that the arrogant assumption that it was had led to much philosophical trouble in physics. It has also been exported, and caused much trouble elsewhere. It was the basis of the twentieth-century denial of causality, in which the whole of philosophy followed the physicists' misguided lead.

If I were to give you three guesses as to where that assumption came from I'm sure you would be right first time – and not by guessing. It came from the already-disproved but still unrejected wave theory of matter. Let us next explore how. WW

* Automatic electronic computers do not make decisions. They are inanimate machines, physical structures driven by energy, which obey a set of instructions or program in a strictly causal, pre-determined way. A program, however, is a metaphysical structure – an expression of a human programmer's will. It is not a tape or a disc, but the information which is stored on tape or disc (it is equally valid in typescript or in the form of a flow diagram). It consumes no energy itself, and it can influence physical events only when it is able to control the operation of a physical computer as intermediary. The analogy with mind and brain is self-evident.

LITERATURE RECEIVED

PCB assembly can be made easier using a Royonic semi-automatic assembly table, according to a brochure describing the system. Components are presented to the assembler in order from a dispenser and their position is indicated by a light spot projected on to the p.c.b. which can draw an outline round the position of an integrated circuit or flash to indicate that polarity needs to be checked for a diode or an electrolytic capacitor. The machine may be programmed by using a joystick or a touch-sensitive pad and the program stored on a floppy disc. Fast assembly of boards with fewer faults is claimed for the system. The brochure is available from W. J. Stickland (Electronics) Ltd, 60 Tower Hill, Chipperfield, Kings Langley, Herts WD4 9LH. WW 400

Recent additions to the Online Conferences 1983 catalogue of conference proceedings. Viewdata 82, Videotex, Local Area Networks and distributed office systems and the Computer Graphics 1982 conferences. Online act as distributors for other publishers including QED Information Sciences and list their publications on data processing and information management. Online Publications Ltd, Argyle House, Northwood Hills, Middlesex HA6 ITS. WW 401

Tools, cases, breadboards, circuit boards and p.c.b. etching patterns are included in the *Hobby Herald*, a catalogue for the "hobby engineer", presented in a newspaper format by BICC-Vero Electronics, Parr, St Helens, Merseyside. WW 402

Specifications, standards and technical documents from the world over are available through a service described in a brochure from London Information (Rowse Muir) Ltd, Index House, Ascot, Berks SL5 7EU. WW 403

Line conditioners to protect computers and other digital systems against noise and voltage variations on a.c. power lines are featured in a leaflet. It includes a selection guide to range of units in the GT series, with detailed information on the electrical parameters which affect the choice of unit. Gould Electronic power conversion Division, Rhosymedre, Wrexham, Clwyd, LL14 4YR. WW 404

Two volumes and over 1,500 pages describe data aquisition products of Analog Devices. The Data Acquisition Databook includes 500 standard products and includes both data sheets and tutorial sections, Products include converters, op amps, conditioners, computing circuits, power supplies, panel instruments, systems and subsystems for measurement and control, and component test systems. Key specifications and applications are given for all the products and a price list is included. Analog Devices Ltd, Central Avenue, East Molesey, Surrey KT8 0SN. WW 405

A glossary of filter terminology and design examples with information on the use of filters in diplexers and multiplexers are included in the Lark Engineering catalogue. Product information includes performance characteristics of bandpass, band reject, tuneable, high and lowpass filters and switchable filter banks. The company uses c.a.d. to produce filters to specified requirements in the frequency range from 12Hz to 18GHz. March Microwave Ltd, 112 South Street, Braintree, Essex. WW 406

Measurement of the suppression characteristics of passive radio interference filters and suppression components is subject to a new Standard, BS6299. The standard specifies methods for measuring insertion loss of passive r.f. filters which may consist of single elements, singly or in combination and either lumped or distributed types. Methods include those for laboratory testing or on a production line tests using fixed impedance terminations. The standard costs £19.50 from BSI sales department, 101 Pentonville Road, London N1 9ND. WW 407