Uncertainty over complementarity?

SIR — Recent publications in *Nature* and elsewhere[1–6] have shown complete disagreement between two respected groups of quantum optics researchers over the answer to the question, "Is complementarity more fundamental than the uncertainty principle?" There are a number of points of conflict between the two groups; our aim is to elucidate the reason for the divergence in their opinions on the particular issue outlined below.

The dispute originally centred on a gedanken experiment proposed by the group of Scully *et al.*[1]. This variation on the Young's double-slit interferometer has two microwave cavities acting as *welcher Weg* ('which path') detectors capable of determining which slit a particle went through. Scully *et al.* claim that there is no random momentum transfer by the microwave fields, so the loss of interference cannot be accounted for by the uncertainty principle. They conclude that complementarity is the more fundamental concept.

In contrast, Storey *et al.* point out that the loss of interference can also be seen as due to a random phase change induced by the detectors[2]. They claim, on the basis of a general theorem, that the physical interpretation of this phase randomization is momentum transfer in excess of $\hbar/d$, where d is the slit separation. Hence, they give priority to the uncertainty relations.

Our reconciliation of the arguments relies on the recognition that there are two different views on what constitutes a random momentum kick. Storey *et al.* define it as a convolution of the momentum wavefunction of a particle $\tilde{\psi}(p)$ with a momentum amplitude transfer function $\tilde{O}_\xi(p)$, where the parameter ξ is the measurement result, according to:

$$\tilde{\psi}_f(p) = N\int dp'\,\tilde{\psi}_i(p-p')\tilde{O}_\xi(p') \qquad (1)$$

where $\tilde{\psi}_i(p)$ and $\tilde{\psi}_f(p)$ are, respectively, the initial and final momentum wavefunctions, and N is a normalization factor. Classically, however, a random momentum kick would result in the convolution of the momentum probability:

$$P_f(p) = \int dp'\,P_i(p-p')\Omega_\xi(p') \qquad (2)$$

It is not difficult to verify that the two concepts of random momentum transfer (equations (1) and (2)) are not equivalent unless $\tilde{O}_\xi(p)$ is nonzero only at a single point; that is, only if there is a unique value of momentum transfer for each ξ. For well-known *welcher Weg* schemes such as the Einstein recoiling slit and Feynman light microscope[7], it is possible to find a measurement basis for the detector such that $\tilde{O}_\xi(p)$ has this property, so that the loss of interference may be interpreted in terms of uncontrolled classical momentum kicks. This momentum disturbance could be seen in the broadening of the diffraction pattern from a single slit.

For the scheme proposed by Scully *et al.*, however, there is no way of measuring the apparatus (the state of the microwave cavities) such that an exact momentum transfer occurs for each result ξ. Thus, although there must be some momentum transfer greater than $\hbar/d$ according to the definition of equation (1) (as shown by Storey *et al.*), there is no random momentum kick in the sense of equation (2), as in previous double-slit experiments. This feature is what makes possible the true novelty in the proposal of Scully *et al.*, namely, that there would be negligible disturbance of the momentum of a particle passing through one slit only. Our analysis should allow similar schemes to be easily identified.

In his debates with Einstein, Bohr used the simple picture of uncontrolled classical momentum kicks to show how the uncertainty principle enforced complementarity[8]. Scully *et al.* have shown that this naive realist interpretation of the uncertainty principle does not work in general. There is thus room for Scully *et al.* to claim that complementarity is more fundamental than the uncertainty principle; but there is also room for claims by Storey *et al.* that one can always consider complementarity as being enforced by the uncertainty principle, if instead the latter is interpreted in terms of the more subtle idea of momentum-kick amplitudes.

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Masculinization costs in hyaenas

SIR — Female baboons *(Papio cynocephalus)* of high social rank may suffer increased rates of miscarriage and infertility compared with lower-ranking females[1,2]. Among spotted hyaenas (*Crocuta crocuta*), adaptations related to dominance seem to entail even more severe reproductive costs, affecting all social ranks. Females of this species display a unique syndrome of behavioural aggressiveness and genital masculinization that is associated with massive prenatal androgen exposure[3,4] and is thought to be an evolutionary response to intense feeding competition[5,6]. Although aggressiveness confers a major fitness advantage to high-ranking females[7], the associated genital masculinization may exact a significant fitness cost.

Spotted hyaenas give birth through the hypertrophied clitoris, similar in size and structure to the male penis[8]. As an adaptation to the severe fighting that occurs between littermates at birth[9], neonates are large and developmentally precocial compared with other carnivores. Maternal and neonatal mortality in primiparous females (those giving birth for the first time) sometimes results when these large fetuses are squeezed through the narrow peniform clitoris.

A typical mammal birth canal extends from the cervix through the pelvis to the external vagina in a relatively straight line. The spotted hyaena birth canal, however, makes a 180° degree bend within the pelvis, and then extends anteroventrally to enter the clitoris (see figure). The birth canal, at 60 cm, is twice the length of that

Calculation of the reduction in potential reproductive success caused by maternal and neonatal mortality in primiparous spotted hyaenas

From field data:
Mean reproductive lifespan of females that survive first reproduction, $L = 8.2$ yr ($n = 32$)
Minimum age at which a cub may survive death of the mother, $s = 1$ yr
Mean interlitter interval, $i = 1.34 \pm 0.03$ yr ($n = 56$ intervals)
Probability of primiparous maternal mortality, $p_m = 0.088$
From captive data:
Mean size of first litter, $n_1 = 1.64$ cubs ($n = 11$ litters)
Mean size of subsequent litters, $n_2 = 2$ cubs[9]
Probability of primiparous neonatal mortality, $p_n = 0.61$
Probability of maternal mortality in primiparae, $p_m = 0.182$
Thus:
Potential reproductive success in absence of mortality due to dystocia in primiparae,
$$RS_p = n_1 + n_2((L-s)/i) = 12.4 \text{ offspring}$$
Realized reproductive success after mortality due to dystocia,
$$RS_r = (1-p_m)(RS_p-n_1p_n) = 10.4 \text{ offspring}$$
(based on field mortality estimate)
or = 9.33 offspring
(based on captive mortality data).