letters

Reality and the quantum theory

There is no need to say how much I have appreciated David Mermin's paper about the Einstein–Podolsky–Rosen question (April, page 38). All the people who participated in our experiment in Orsay are indeed very glad that Mermin quotes our work as "providing the experimental answer to Einstein's challenge." However, I want to acknowledge all that we owe to the early realizations of EPR situations with optical photons by John F. Clauser and Stuart Freedman at Berkeley, Richard Holt and Francis M. Pipkin at Harvard, and Edward S. Fry and Randall C. Thompson at Texas A & M University.

Thanks are due for all the information that we found in their various reports and theses, for their friendly advice, and even for loan of some equipment—all of which helped us to build the second-generation apparatus. And also the results obtained by these researchers were already a good indication of the answer, as were the results of the experiments with positronium-annihilation γ rays.

May I slightly correct Mermin, and say rather that the ensemble of all our experiments "provide[s] the experimental answer to Einstein's challenge."

ALAIN ASPECT
Institut d'Optique Théorique et Appliquée
5/85 *Orsay, France*

•

David Mermin's article, "Is the moon there when nobody looks? Reality and the quantum theory" (April, page 38), has a useful pedagogic role, and may even succeed in shifting a few physicists from Type 2 ("rocks in the head") to Type 1. We agree with Mermin most heartily on the importance of Bell's theorem. It has made it possible to move the Einstein–Podolsky–Rosen thought experiment substantially closer to the domain of the laboratory. Where we would differ from Mermin's analysis is in our assessment of the real experiments thus far performed, such as the Aspect series.[1]

Among experts there is a widely recognized inadequacy, usually referred to as "the loophole," in these experiments. It arises[2] because the vast majority (more than 95%) of all signals emitted by the calcium atoms are not detected by the photomultipliers. Because one has to analyze coincidences, well over 99% of all cascade signals are not analyzed. So can one be sure that the coincidences actually analyzed constitute a fair sample from the cascade population? We believe that one's assessment of the importance of this question depends strongly on whether one belongs to Mermin's Type 1 or Type 2.

We have shown[3] that a plausible model exists that explains the data in all cascade experiments performed to date. To illustrate how such models work, we show the effect of introducing real detectors into Mermin's "experiment." He allows only eight different "real" signals: RRR, RRG, RGR, GRR, RGG, GRG, GGR and GGG.

For a given signal λ, he considers the conditional detection probability, $M_\lambda{}^i(\mathrm{R})$, for receiving an R result when the signal is processed with the polarizer in position i. His fatal, oversimplifying assumptions are:

- That M is always zero or one (the detection process is said to be "deterministic")
- That $M_\lambda{}^i(\mathrm{R}) + M_\lambda{}^i(\mathrm{G}) = 1$, corresponding to perfect detectors.

Consider first a model in which the second assumption no longer holds. There are six signals: RGO, ROG, GRO, GOR, OGR and ORG. We assume these are all equally probable. The detection probabilities are:

$$M^1_{\mathrm{RGO}}(\mathrm{R}) = 1,\ M^2_{\mathrm{RGO}}(\mathrm{G}) = 1,$$
$$M^3_{\mathrm{RGO}}(\mathrm{R\ or\ G}) = 0$$

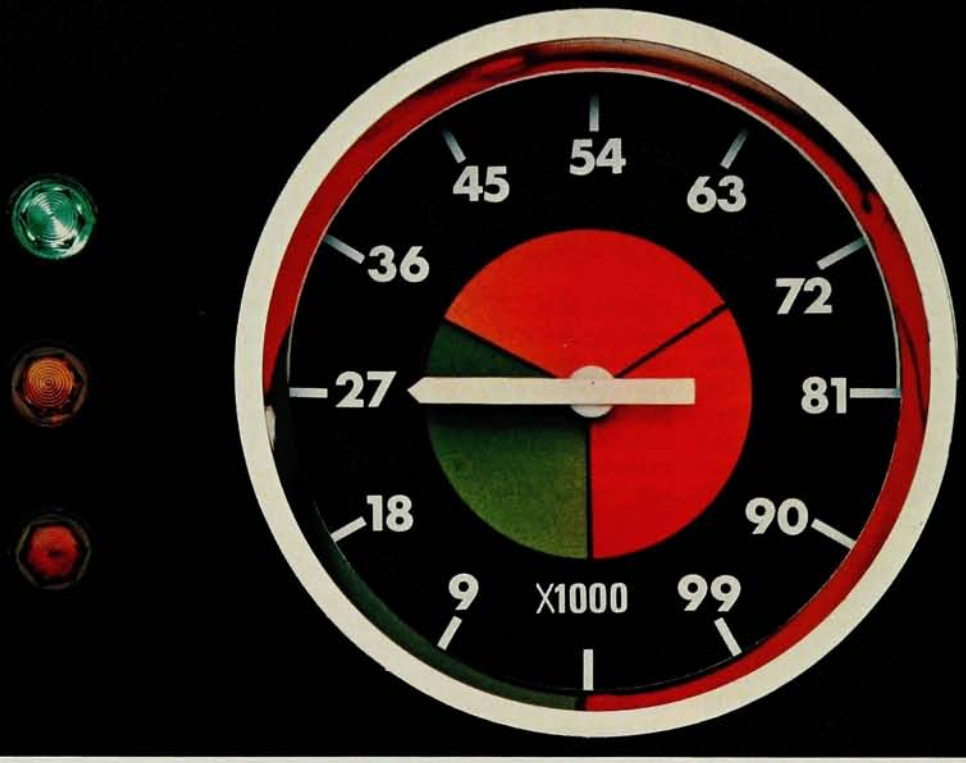
and so on. It is now easy to see that the coincidence frequencies with 11 and 12 settings are proportional to:

$$P_{11}(\mathrm{R}) = \tfrac{1}{3},\quad P_{11}(\mathrm{RG}) = 0,$$
$$P_{12}(\mathrm{RG}) = \tfrac{1}{6},\quad P_{12}(\mathrm{RR}) = 0$$

with the same (123) and (RG) symmetries as in Mermin's model. These frequencies satisfy the pair of conditions that Mermin says cannot be satisfied in a realistic model: There are no RG events when the setting is 11,

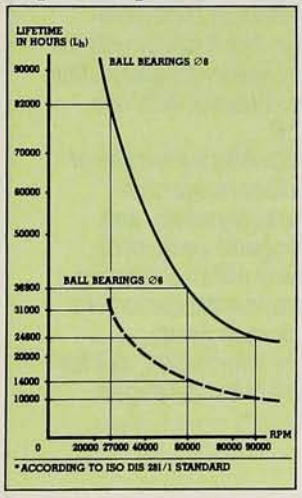
ALCATEL TURBOMOLECULAR PUMPS

27 000 rpm



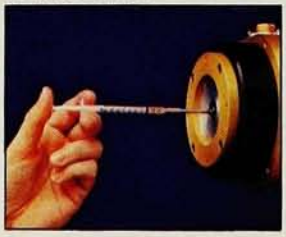
minimum rotational speed for maximum reliability

■ **Theoretical ball bearings life time expectancy**



■ **Performance in any orientation**

■ **Totally field serviceable**



a full line of pumps ranging from 80 to 400 ls-1

Alcatel Vacuum Products, Inc.
40 Pond Park Road
Hingham, MA 02043,
Tel: 617-749-8710

IN EUROPE:
CIT-Alcatel High Vacuum Division
33, rue Emeriau, 75725 Paris, Cedex 15.
France. Tel: 571.10.10

CIT Alcatel **ALCATEL VACUUM PRODUCTS**

Please forward more detailled information on Alcatel's Turbomolecular Vacuum Pumps ☐

Please contact me ☐

Send your business card to Alcatel Vacuum Products, Inc.

Visit Alcatel in Booth Island A, AVS, Houston, TX

MRS SHOW-BOOTH #302

Circle number 10 on Reader Service Card

letters

and the overall RG count is the same as RR, because

$$p_{11}(\mathrm{RR}) + 2p_{12}(\mathrm{RR}) = p_{11}(\mathrm{RG}) + 2p_{12}(\mathrm{RG})$$

Note that this model, like all those considered by Mermin, is deterministic.

Secondly we consider a model with six equally probable signals: GGR, GRG, RRG, RGR and GRR. The detection probabilities are

$$M^1_{\mathrm{GGR}}(\mathrm{G}) = 1/2 = M^2_{\mathrm{GGR}}(\mathrm{G}),$$
$$M^3_{\mathrm{GGR}}(\mathrm{G}) = 0, \quad M^3_{\mathrm{GGR}}(\mathrm{R}) = 1$$

and so on. This model satisfies neither assumption. It is "stochastic." For the coincidence rates it gives:

$$p_{11}(\mathrm{RR}) = 1/2, \quad p_{11}(\mathrm{RG}) = 0,$$
$$p_{12}(\mathrm{RR}) = 1/12, \quad p_{12}(\mathrm{RG}) = 1/3$$

which again satisfies Mermin's two conditions.

Neither of these two simple models reproduces exactly the frequencies predicted by quantum mechanics for such an ideal experiment. These frequencies are:

$$p_{11}(\mathrm{RR}) = 1/2, \quad p_{11}(\mathrm{RG}) = 0,$$
$$p_{12}(\mathrm{RR}) = 1/8, \quad p_{12}(\mathrm{RG}) = 3/8$$

Mermin, for good pedagogic reasons, confined his attention to two features of this model, which together, he claims, can not be reproduced by a realistic model. The above two realistic models show that Mermin's theorem no longer holds if the detectors are real. In spite of its simplicity, our second model is substantially closer to the quantum model than is our first model. With a somewhat more sophisticated set of λ, it is possible to get so close to the quantum model that the counting statistics from all existing experiments are inadequate[4] to separate them.

Whether a serious attempt is ever made to achieve such a separation will depend on the representations of Type 1 and Type 2 among the financially powerful members of our profession.

In our opinion, progress will be obtained by either finding experimental tests in which the detection rate is high enough to make possible a genuine test of the Bell inequalities, or by proposing reasonable supplementary hypotheses[4] that will allow us to derive more readily testable inequalities.

References

1. A. Aspect, P. Grangier, G. Roger, Phys. Rev. Lett. **47**, 460 (1981); **49**, 91 (1982). A. Aspect, J. Dalibard, G. Roger, Phys. Rev. Lett. **49**, 1804 (1982).
2. J. F. Clauser, M. A. Horne, Phys. Rev. D **10**, 526 (1974).
3. T. W. Marshall, E. Santos, F. Selleri, Phys. Lett. **98A**, 5 (1983).
4. T. W. Marshall, Phys. Lett. **99A**, 163 (1983); **100A**, 225 (1984).
5. T. K. Lo, A. Shimony, Phys. Rev. A **23**, 3003 (1981); E. Santos, Phys. Rev. A **30**, 2128 (1984); A. Shimony, Phys. Rev. A **30**, 2130 (1984).

T. W. Marshall
E. Santos
Universidad de Santander
Spain

5/85

•

The article by David Mermin does not give enough detail to substantiate that the laboratory experiment is a simulation of the thought experiment. Specifically, the thought experiment uses an ideal source and two ideal detectors that cannot exist in practice. In the laboratory, each source–detector combination has an implicit probability that an emitted particle will traverse the detector-sensitive volume and, given traversal, produce a response. If this probability approaches unity, detector responses to a coherent many-particle source are necessarily multiple-particle responses.

If the laboratory experiment measured individual particles in two detectors, then the experiment must also have measured many null and single-detector events (not mentioned in the article). With the possibility of null and single-detector events, the experimentally observed statistics on the paired events are readily explained. In essence, particles have specific properties (labels) with an observability that depends upon the properties. Unobserved particles simply add to the null and single-event data.

For two-property (R or G) three-channel detector pairs, and G1G2R3-labeled particles, the observability matrix

1/6 G1G1	1/3 G1G2	1/2 G1R3
1/3 G2G1	1/6 G2G2	1/2 G2R3
1/2 R3G1	1/2 R3G2	1 R3R3

matches the experimental data of the article after permutations and combinations for other labels, provided that R1R2R3 and G1G2G3 particles are never observed if they exist.

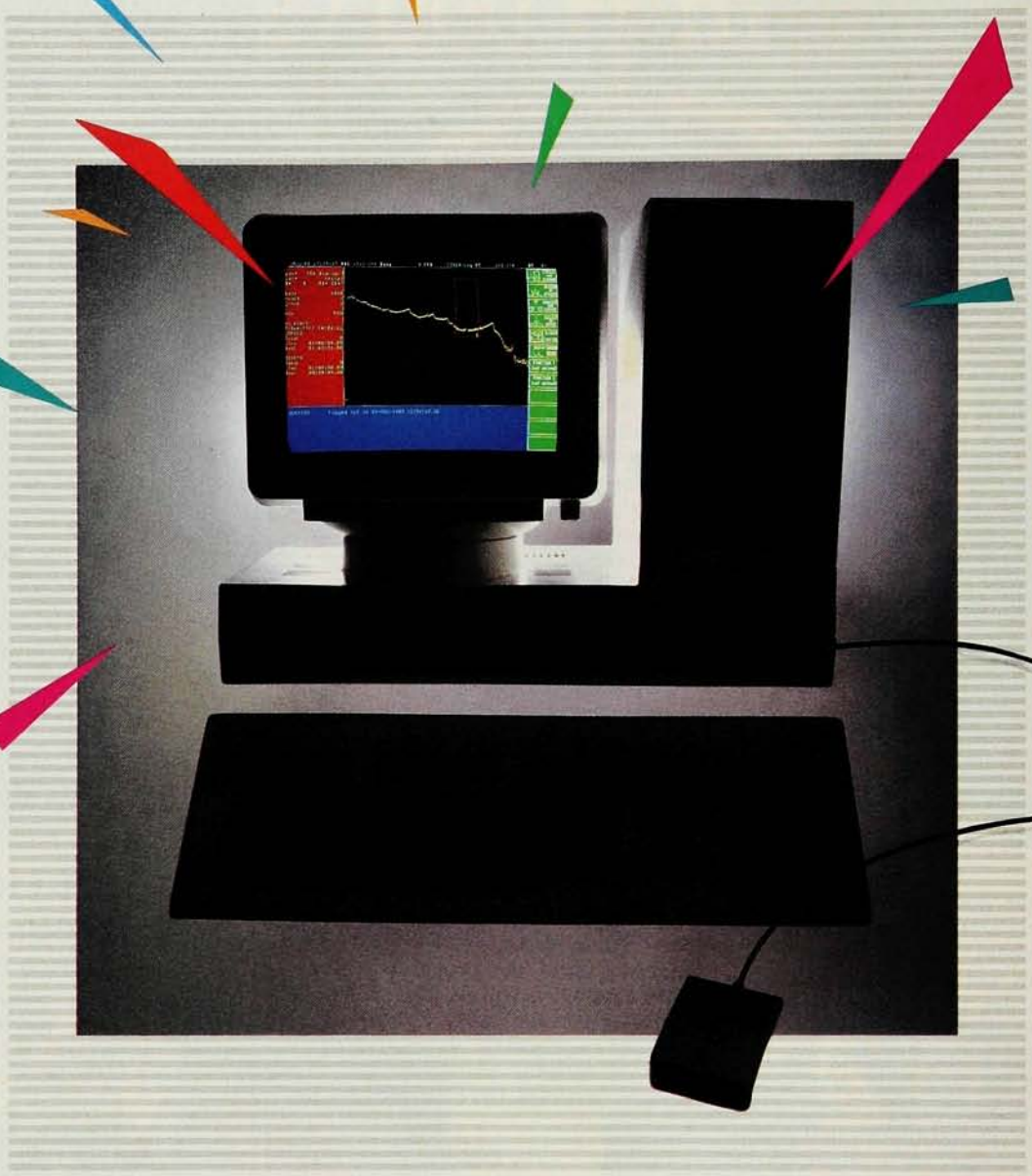
In conclusion, the article is not convincing that prelabeled particles are incompatible with experimental observations. If the two detectors always respond to source emission, then the detectors are not measuring paired single-particle events. If the detectors have null and single-event responses, the experimental data can be explained by relative observables.

Thomas M. Jordan
Northridge, California

5/85

•

In the April isssue of PHYSICS TODAY there is a most interesting paper by David Mermin on the nonlocality problem raised by the quantum-mechanical



N D 9 9 0 0

G E N I E

Unleash the Real Power of the MicroVAX in your Laboratory

The new ND9900 System offers: Fully integrated data acquisition, display and analysis Ultrafast, simultaneous data acquisition from up to 32 ADC's New design terminal with mouse for quick and easy display manipulation and function execution Independent data acquisition and display processors MicroVAX II CPU with MicroVMS Multi-user OS Extensive library of applications and 3rd party software Reliable, high-speed communications to remote multi channel analyzers.

Call our ND9900 Product Specialists at 312/ 884-3621 and find out how to unleash the power of the MicroVAX II in your laboratory.

Instrumentation Division
Golf and Meacham Roads
Schaumburg, Illinois 60196
Tel: 312-884-3621

Nuclear Data Inc

violation of Bell's inequality, which has been experimentally proven by Alain Aspect and his coworkers in a very convincing way.

Although I find that Mermin's *gedanken* experiment gives an extremely lucid (and entertaining) exposition of the subject, there is one big question left in my mind as regards the comparison of Mermin's device to the real experimental situation. It is emphasized very strongly in the article that there are no connections between the pieces. However, having studied the papers of Aspect *et al.*, I'm left with the impression that there are indeed connections that are plainly visible to the naked eye, namely the wires connecting the single-photon detectors to a set of "central black boxes" such as coincidence counters and a time-to-amplitude converter. As far as I have understood, the careful calibration of the coincidence window to the temporal sequence of single detections by choosing wires of appropriate lengths is a crucial feature of the experiments.

Now, Mermin claims in a parenthetic remark that when we have learned what is inside the black boxes (by which I assume he means the particle source and the single detectors) we will agree that there are no connections. I'm very intrigued by this remark because it seems to suggest that the wires in the real world that are so seemingly solid and present in the experiments are just an apparition of a spooky nature. Perhaps I should interpret the remark as saying that everybody who knows a little of quantum mechanics will know that the wires are irrelevant. I have lectured on the subject of quantum mechanics at the University of Copenhagen and have seen a couple of textbooks, but nowhere have I found something that justifies the claim that wires are irrelevant. On the contrary I find that Niels Bohr's refutations of Albert Einstein's thought experiments from the Solvay meetings of 1927–30 all stressed that even the macroscopic parts of measuring equipment are subject to quantum uncertainties.

Maybe there is something quite elementary that I have overlooked. I would therefore be very happy if somebody could enlighten me and clarify just what it is that I missed. I think that Mermin's article is a very valuable contribution to the popularization of a difficult problem, but it would be even better if we got a clear answer to the question formulated above, which might conceivably spontaneously arise from an inexperienced listener.

PEDER VOETMANN CHRISTIANSEN
Institute of Mathematics and Physics
Roskilde University Center
6/85 *Roskilde, Denmark*

•

David Mermin deserves our congratulations and admiration for the very fine article "Is the moon there when nobody looks? Reality and the quantum theory." Many people have tried to bring home to the general reader, as well as the scientists, the "weirdness" of the quantum world and the "spooky actions" that seem to take place there. But no one has done it better. Too many physicists are guilty of accepting these matters in a somewhat blasé attitude, pointing at the mathematical formalism of quantum mechanics as if that would suffice for an explanation. Mermin's brave efforts have in the past reached[1] the readers of the *American Journal of Physics* as well as the *Journal of Philosophy*. The founders of quantum mechanics were fully aware of the conceptual revolution inherent in this subject. But today, unfortunately, only a very small fraction of physicists show interest in the interpretation of quantum mechanics or are even aware of the problems involved. That is why Mermin's article in PHYSICS TODAY is so important.

Quantum mechanics indeed seems to refer to a world of magic. And the general public is duly impressed by it. So is the magician watching a magic trick performed. But such a magician also wants to know what's behind the trick. Mermin's paper stops short of that. It was not intended for that purpose.

And so, it might be appropriate to indicate just very briefly what an analysis of an Einstein–Rosen–Podolsky thought experiment involves. This year is the 50th anniversary of that faith-shaking publication,[2] and so is one more reason to pay attention to it.

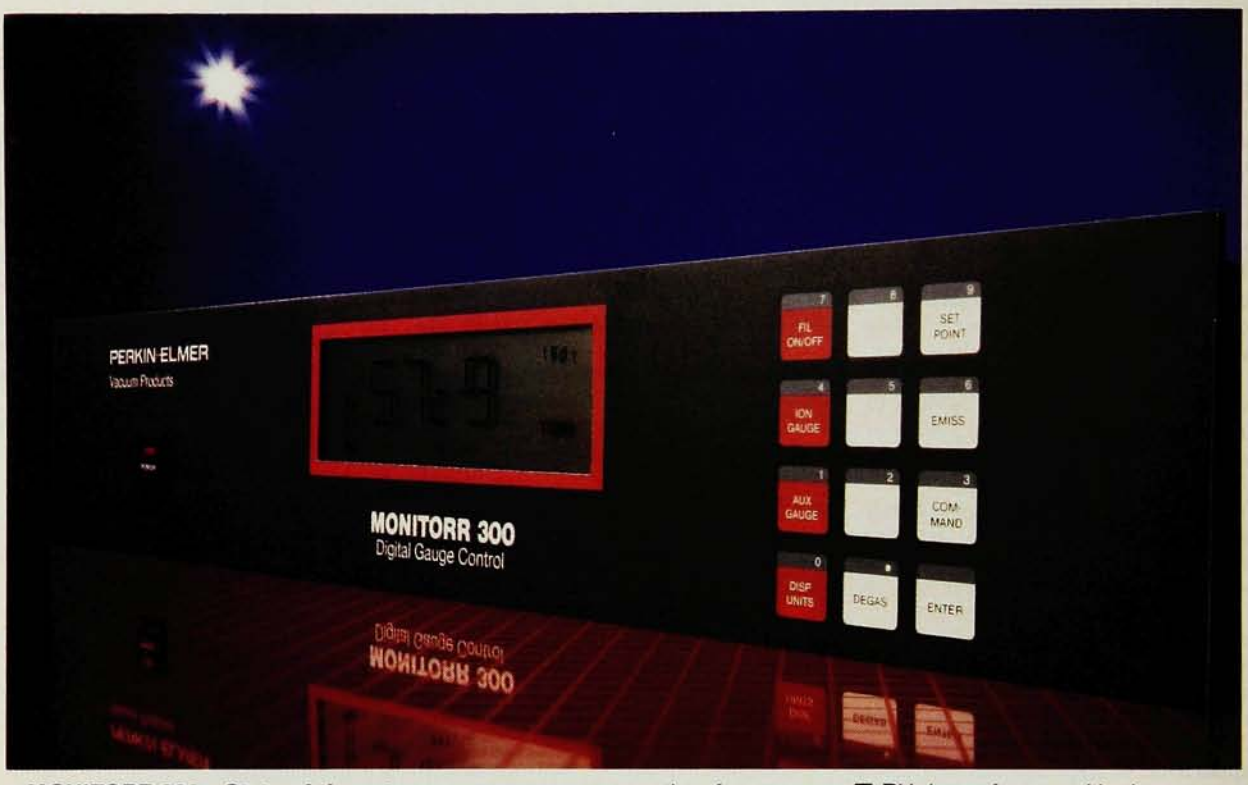
There are three main components:

▶ An unpolarized electron has spin component $\frac{1}{2}\hbar$ in any direction a Stern–Gerlach analyzer chooses to probe. Similarly, every photon of an unpolarized beam emerges polarized after interaction with a polarizer. Both are typical quantum phenomena. They preclude a classical picture of those quantum particles: These particles do not have a definite polarization before entering the apparatus.

▶ All classical conservation laws of energy, momentum and angular momentum continue to hold at all times also in quantum mechanics (contrary to what some people suggested in the very early days of the theory). This fact, taken together with the previous one, implies that a singlet state of the two particles will yield "equal colors for equal settings" in Mermin's model *without the need for communication between the two detectors.*

▶ The superposition principle rules

The new MONITORR™ 300 gauge control—performance and value unmatched in the industry.



MONITORR 300—State-of-the-art technology.

Introducing the MONITORR 300, for use in high vacuum applications where accurate measurement and process control are a necessity.

The MONITORR 300 incorporates state-of-the-art technology and reliability, both inside and out. The clean, uncomplicated high tech exterior design is only the beginning. Inside lie the brains and brawn of the unit—a powerful 32 bit microprocessor; ready to serve your needs today and accommodate future expandability.

Add options as needs expand.

You may later want to add the IEEE-488 computer interface option for on-line data handling and remote control of all functions from an external computer. Or, if you need greater system automation, four optional process control setpoints are available.

Outstanding feature/price relationship.

The MONITORR 300 features you get for the price make it an outstanding value in today's market.

- Digital pressure readout in torr, pascal, or millibar units.
- Arrows on LCD indicate rising and falling pressure trends at a glance.
- Large LCD displays pressure from 1 torr (using thermocouple option) to 10^{-9} torr.
- Keyboard adjustable emission calibration.
- Automatic filament shut-off prevents high pressure "burn-out."
- Complete protection against gauge tube malfunctions.
- RH degas for use with glass encapsulated gauge tubes.
- Analog output for use with chart recorders.
- IEEE-488 computer interface option.
- Four optional process control setpoints.

You're probably saying, "Looks great, but how much?" Well, we'll give you a hint—it's under $1,000!

For complete information, simply write "MONITORR 300" on the back of your business card and send it to us. You'll be glad you did.

Perkin-Elmer Vacuum Products
6509 Flying Cloud Drive
Eden Prairie, MN 55344
(612) 828-6190

Circle number 14 on Reader Service Card

PERKIN-ELMER

supreme in the quantum world (barring superselection rules): The relative phases of wavefunctions produce statistical correlations that are completely unheard of in classical physics and irreproducible on the classical level. Quantum correlations are qualitatively and quantitatively different from classical ones. In the model of the EPR experiment, equal colors flash just as often as unequal colors, while in a classical model equal colors have to flash more often.

These points indicate[3] some of the ways in which quantum reality differs from classical reality. But they do not take away from our wonder at the "magic" of the quantum world because we are children of a classical world in which nothing of an analogous nature exists.

References

1. D. Mermin, Am. J. Phys. **49**, 940 (1981); J. Philosophy **78**, 397 (1981).
2. A. Einstein, B. Podolsky, N. Rosen, Phys. Rev. **47**, 777 (1935).
3. F. Rohrlich, Science **221**, 1251 (1983).

F. Rohrlich
Syracuse University

4/85

•

Mermin gives a remarkably simple illustration of Bell's theorem but, unfortunately, leaves the impression that something mysterious is implied. The situation is much simpler: The pair of photons considered by Mermin behaves[1] as a single, nonlocal, indivisible entity. Everyone is familiar with the idea that a single photon is nonlocal. This is why it can pass through two slits and interfere with itself. A single photon may even originate[2] in two different lasers. Likewise, a photon pair behaves, under some circumstances, as a single entity. If anything here is curious, it is that most dynamical variables of Mermin's photon pair behave as if these were two separate particles, with reasonably well-defined positions and momenta. However, some of their variables, namely the polarizations, are inseparably entangled. It is only because we force upon the photon pair the description of two separate particles that we get the paradox of Einstein, Podolsky and Rosen.

References

1. A. Peres, Am. J. Phys. **52**, 644 (1984); Found. Phys. **14**, 1131 (1984).
2. R. L. Pfleegor, L. Mandel, Phys. Rev. **159**, 1084 (1967).

Susan J. Feingold
Asher Peres
Technion, Israel Institute of Technology
Haifa, Israel

6/85

•

Is David Mermin there when I am not reading his paper or writing a letter disagreeing with it?

As someone with rocks in his head, Type 2a, I find his unreal article "Reality and the quantum theory" a lot of fun, but nevertheless, or perhaps therefore, somewhat disturbing. This is not to say there is anything wrong with it. It's just that it (appears to) disagree with my own view,[1] which is something I always find rather disturbing.

Quantum mechanics is nonintuitive but it is not weird. The weirdness arises when someone (perhaps an outstanding physicist) misunderstands a point, oversimplifies, leaves an essential aspect out, uses meaningless words incorrectly or does something else wrong. It is, in fact, often very easy to do something wrong in quantum mechanics and arrive at a strange result. But this is not inherent in the subject, just in the way it is mishandled. Quantum mechanics, being subtle, requires great care (which may be one of the points of the article). Quantum mechanics is subtle but it is not malicious.

This provides a way of testing how much someone understands quantum mechanics (or any other part of physics). The stranger he makes it sound, the less he understands it.

Actually I really don't understand all the fuss about the EPR paradox and Bell's theorem. The article has an example of an experiment that mixes classical and quantum views (to help us lay aside our quantum prejudices, which is like giving a Buddhist example of a Torah discussion to help us lay aside our Jewish prejudices). That this may seem a little strange is not surprising.

Is quantum mechanics there if you don't explicitly consider it?

In quantum mechanics probabilities are found by adding probability amplitudes, not probabilities. This may not be what we expected, but that is the way it is. Is it really strange? The example merely shows that someone who is used to adding probabilities will be surprised at his results when he has to add amplitudes. But that is not the fault of Nature. And this does not make quantum mechanics weird. (Actually, upon consideration it is classical physics and the addition of probabilities rather than amplitudes that is weird.)

One of the reasons for difficulties with the EPR paradox is that often people start with some bizarre assumption (so it is not surprising that the results are weird), like the magnets being uncorrelated. But they must be correlated (say, by the experimenter) for there to be any meaningful results

continued on page 136

letters

continued from page 15

from the experiment. The statement "entirely decoupled polarizers . . . identically aligned" is[1] self-contradictory (an oxymoron). Anyone who does not understand this last point can read the reference listed,[1] where he will undoubtedly find so many things he does not understand he will not have time to worry about this point.

Does all this really matter? To someone who has spent a lot of time teaching physics (or at least trying to) the answer is yes. People want to believe the world is weird, strange, incomprehensible. They do not need our help to think this way. But it is important that they understand how nature works and realize why we believe that nature is comprehensible. It is simply wrong to let people think it is not.

The article was interesting, and informative and challenging to those who understand its spirit. But one must be careful not to mislead those not knowledgeable enough to understand what is being said (and unfortunately some of these are physicists).

Reference

1. R. Mirman, Nuovo Cimento **16B**, 398 (1973).

RONALD MIRMAN
5/85 *New York, New York*

●

I am very grateful for David Mermin's article; for the first time I have understood what Bell's theorem is all about. I agree that Einstein would have been puzzled and disturbed by it—not by the results of the EPR (since he accepted quantum mechanical formalism and would have expected experiments to verify the correlation), but by the ruling out of hidden local variables by Bell's theorem.

I write, though, to suggest a parlor game version of your model of the receptors with the red and green lights. Let two people stand in a room, each facing a wall with their backs to each other. On the wall in front is a spinner that can stop at 1, 2 or 3 with equal probability. We assume they cannot communicate with each other in any way. I have a deck of cards, each bearing the same set of instructions. I hand them out in pairs, one to each person. What set of instructions on the cards will produce the following result?

▶ When both spinners show the same number, each person will raise the same hand (left or right)

▶ When the spinners mismatch in numbers, their hands may or may not match

▶ In the long run, their raised hands will match half the time, and mismatch half the time.

Following Mermin's arguments, we can accomplish the first result by assuming the cards come in eight varieties, each with one of the eight combinations of L and R on it, and that duplicate cards are handed out each time. But can we devise a plan that will guarantee the third result? I pass this model along for whatever it is worth. It turns the EPR paradox into a puzzle that might actually make an entertaining party pastime.

MARTIN GARDNER
5/85 *Hendersonville, North Carolina*

●

I found David Mermin's article to be particularly interesting because of its relevance to the education of my young son (age 7 months). He is at the age at which he is supposed to be unlearning some of the notions of quantum mechanics discussed in the article. Child development experts suggest that I should be playing peek-a-boo-like games with him so that he can discover that objects retain their identity, even when they are not being observed. As a physicist, perhaps I should refrain from playing peek-a-boo with him until he is old enough to place the game in its proper context, that is, the classical approximation.

KENNETH E. EKSTRAND
Bowman Gray School of Medicine
Wake Forest University
5/85 *Winston–Salem, North Carolina*

●

In his article David Mermin has presented his perspicuous exposition of the inseparability that follows from Bell's theorem and the results of correlation experiments. The article comes soon after the recent analysis[1] by Jon Jarrett of the experimentally violated Bell locality condition into preparation independence and outcome independence (one of which, probably the latter, must be forsaken). That is, the conjunction of the following two independent conditions must be denied: If spacetime region A has a spacelike separation from spacetime region B, then the results of measurement in A must always be

▶ causally independent of the choice, implemented in B, of which quantity is to be measured in B and also

▶ causally independent of the outcome of any measurement performed in B.

Together, Mermin's explication and Jarrett's results have contributed to a revival of interest in quantum wholeness, leading me to dig out, for some colleagues, a correlation I composed some years ago. Perhaps your readers would also enjoy it:

Metaphysical wholeness, 1623–1978

Meditation XVII

Now this bell tolling softly for another, says to me,
Thou must die.

letters

No man is an island, entire of itself:
every man is a piece of the continent,
a part of the main.
If a clod be washed away by the sea,
Europe is the less,
as well as if a promontory were,
as well as if a manor of thy friend's or of thine own were.
Any man's death diminishes me because I am involved in mankind,
and therefore never send to know for whom the bell tolls;
it tolls for thee.

John Donne

Comprehension of unity

Now Bell's theorem holding firmly for another test, says to me,
Thou must compose.
Nothing is isolated, entire of itself;
every subsystem is a component of the cosmos,
correlated with all else.
If a photon be measured by me,
the universe is reduced,
as well as if an apparatus were,
as well as if the mind of Wigner's friend or of thine own were.
Any property's determination reduces me because I am inseparable from the whole,
and therefore never signal to know for whom Bell's theorem holds;
it holds for thee.

Howsit Done?

Reference

1. J. P. Jarrett, Nous **18**, 569 (1983).

ANDRE MIRABELLI
Saint Peter's College
Jersey City, New Jersey

5/85

DAVID MERMIN REPLIES: T. W. Marshall and E. Santos, Thomas M. Jordan and Peder Voetmann Christiansen all make a similar point, which was also put very neatly in a private letter from Kenneth R. Brownstein. The actual experiments in Orsay differ from my *gedanken* demonstration in one important way. To make the demonstration correspond more closely to the real experiments, it is necessary to add that there are many runs in which only one of the two detectors signals an event. The data I describe are collected only from those runs in which both detectors flash. Another way of putting this is to note that in the real experiments there are connections in the form of coincidence counters that are responsible for single-event runs being unrecorded.

Is this a relevant connection? Certainly not if you believe in quantum mechanics. But if you really, deep in your heart, believe that quantum mechanics gives the last word on the subject, then you are unlikely to be interested in the experiments at all. If you regard the experiments as relevant, then you have to regard the connection as relevant. The detailed analysis of the Orsay experiments disposes of this complication by certain

Some very interesting developments in Medium Energy Ion Scattering ask for your attention.

The depth resolution of the High Voltage Engineering System for Medium Energy Ion Scattering (MEIS) is 3-4 Å.
This figure is an order of magnitude beyond the capability of conventional Rutherford backscattering when using a surface barrier detector.
In surface analysis techniques depth resolution is not the only parameter of importance. Consider then a few other attractions, we offer as well:

- The energy resolution of our Toroïdal Electrostatic Analyser is 4×10^{-3} at an acceptance angle of 30°.
  This large acceptance angle decreases the measuring time by approximately a factor of 30. As a consequence, damage due to ion beam dose and contamination is greatly reduced.
  The angle resolution after position sensitive detection is $\leqslant 0.3°$.
- Our newly developed UHV target manipulator can rotate a sample around three independent axes by means of two linear movements and one rotary movement driven by stepping motors outside the vacuum. In addition to the rotations, there are provisions to shift the sample along 3 axes. The sample holder plugs into the manipulator head and has a heating arrangement for the sample of up to 1200°C.
- The sample loading chamber accepts 7 sample holders which can be inserted into the sample manipulator head without opening the UHV chamber.
- The operating vacuum of the system is 10^{-10} torr.

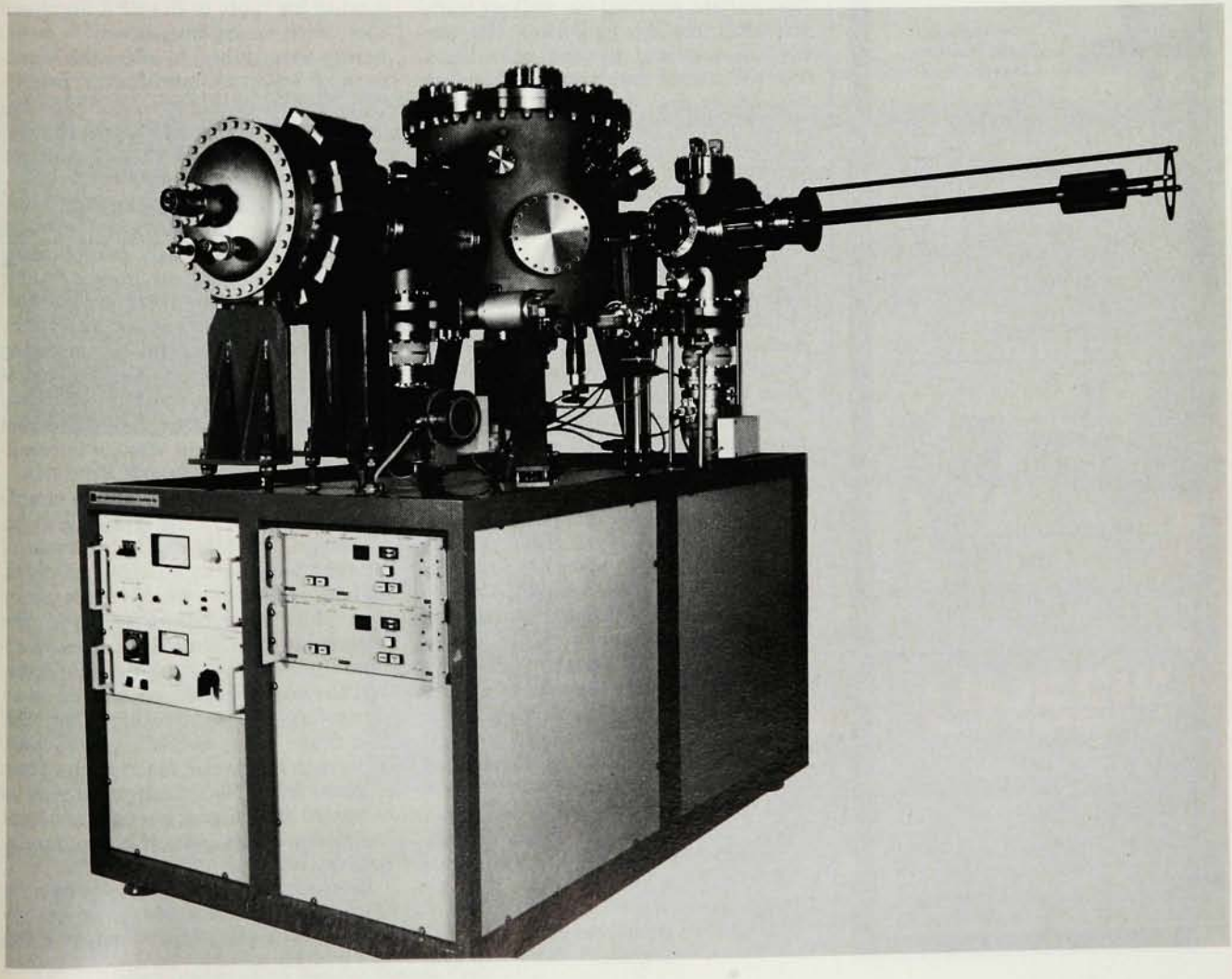
A visit to our booth no. 909 at the MRS show is the most expeditious way to get specific data relevant to your work.

HIGH VOLTAGE ENGINEERING EUROPA BV

P.O. Box 99 - 3800 AB Amersfoort
The Netherlands
Phone: 33 19741 - Telex: 79100

Circle number 92 on Reader Service Card

For example, we have just improved depth resolution by an order of magnitude.



letters

extremely reasonable subsidiary assumptions, which, however, one could certainly imagine might be violated in some not unreasonable hidden-variable theory.

In the context of my *gedanken* demonstration, Marshall and Santos point out that this connection can be exploited to construct instruction sets that yield the most important features of the data I describe, and Jordan and Brownstein point out that it can be exploited to construct instruction sets giving every feature of those data.

The trick is easily done, in any number of ways, by having in addition to the instructions R (detector flashes red) and G (detector flashes green) a third instruction, X (detector fails to respond in any way). Thanks to the coincidence counters, if either detector is set to a number for which the instruction it receives is X, no event is recorded at either end. (In this model the particles need not carry identical instruction sets in each run.)

In fact this loophole is big enough to let through an instruction-set model that accounts for any distribution of results whatever, including statistics that violate physical (as well as metaphysical) locality, exploiting the connection provided by the coincidence counter to send real messages from one detector to the other.

To produce any data you want, you need only require that all instruction sets have X's in two of their three positions. The third ("colored") positions in a pair of instruction sets can be any of the nine possibilities $ij = 11, 12, 13, 21, \ldots$ with equal probability. The values of the colors appearing on those instruction sets that are colored in positions ij are determined by whatever distribution one wishes to produce when the switches are set to i and j.

Of course this model has the observational consequence that single events, even for perfectly positioned ideal detectors, will occur eight times as often as coincidences. It is my guess that with some hard analysis and perhaps a few reasonable symmetry assumptions (such as rotational invariance) one ought to be able to rule out this kind of explanation without having to appeal to "the financially powerful members of our profession" to support even more refined experiments than the one done in Orsay. But I haven't yet figured out how to do this, and the point made by Marshall and the others is certainly a valid refutation of the claim one sometimes reads: that the Orsay experiments have ruled out even the *logical possibility* of a local realistic description of the correlations.

Another group of letters (Fritz Rohrlich, Susan Feingold, Asher Peres and Ronald Mirman) argue that if you look at the *gedanken* demonstration correctly the mystery disappears. Rohrlich concisely summarizes the quantum theoretic view. I wouldn't say, though, that his formulation reveals "what's behind the trick." It simply presents the facts of the experiment in a way that makes it easy not to notice that anything tricky might be going on. The trick comes back into view when you ask how the conservation law can possibly be implemented without communication between the two detectors, in view of the fact that the particles do not have a definite polarization before entering the apparatus.

The wonderful thing about the mathematical formalism of the quantum theory is that if one sticks strictly to that formalism and eschews all verbal formulations then one no longer even has the choice of whether or not to make things look tricky. The tricky point of view simply cannot be expressed. The formalism assigns no meaning whatever to the "implementation" of a conservation law and there is no way to ask the question—no room to be tricky.

My guess is that Bohr had something like this in mind when he wrote at the start of his reply to the EPR argument that "such an argumentation . . . would hardly seem suited to affect the soundness of quantum-mechanical description, which is based on a coherent mathematical formalism covering automatically any procedure of measurement like that indicated."

If you stick strictly to the mathematical formalism, there's no real problem. Any attempt at verbally paraphrasing the formalism, however, invites trouble because it induces other verbal constructions that make things look tricky but do not correspond to anything expressible in the formalism. That is why the position of the Type 2b physicists (not bothered by Bell's theorem but refuse to explain why) is unassailable.

I also entirely agree with the simple characterization of the situation given by Feingold and Peres, that the pair of photons behaves as a single, nonlocal, indivisible entity. But I don't agree that this formulation removes the impression that something is mysterious. Indeed, I would have characterized the *gedanken* demonstration as an elementary demonstration that the data make it impossible for us to force upon such a pair the description of two separate particles, thereby requiring us to regard the pair as a single nonlocal indivisible entity, which is profoundly mysterious.

Like Mirman, I've also devoted a lot of time and effort to trying to demystify physics; that was what I thought I was doing in my article. To me the appeal

letters

of Bell's theorem is that it offers a way to give people who don't know anything at all about quantum mechanics a simple explicit illustration of just what it is that makes quantum correlations so striking. The "quantum prejudices" I asked people to put aside were not prejudices about how the world behaves, but prejudices about what is or is not remarkable.

As one who let his *Scientific American* subscription lapse when Martin Gardner retired, I'm delighted to have enlightened him on what Bell's theorem is all about, but with parlor games like the one he proposes, he's going to have trouble getting anybody to attend his parties.

I applaud Kenneth Ekstrand's insight into the pernicious influence on the development of physical intuition of an early exposure to peek-a-boo. He has a profound point. My own view is that there *is* a real problem, but that the answer to the problem is to be sought not in a better understanding of the physical world, but in a better understanding of how we seem to have to think about that world.

I believe we should all be grateful to Andre Mirabelli for bringing to our attention John Donne's spiritual brother Howsit and his school of Quantumphysical Poetry.

And, finally, I would like to note that Jack Sarfatti wrote me to say that he is the author of the communication I cited from the California think-tank director to the undersecretary of Defense for research and engineering. I am glad to acknowledge the original source.

DAVID MERMIN
Cornell Uneversity
Ithaca, New York

7/85

Nuclear power plant accidents

Barbara G. Levi presented a concise overview of some current problems in nuclear power plant regulation in her article, "Radionuclide releases from severe accidents at nuclear power plants (May, page 67). A few of the statements in this otherwise excellent article are either incorrect or likely to be misinterpreted by your readers, however, and should be clarified.

The statement "Most current regulations rely on a slight modification of that source term—100% of the noble gases, 50% of the iodine and 1% of the remaining fission products" appears in the midst of a discussion of severe accidents. The stated composition, however, is the fission-product release assumed to be dispersed in a containment building as a means of assessing the adequacy of that building's design