

Interaction-free measurement for a macroscopic quantum system under decoherence

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Interaction-free measurement

Model

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Interaction-free measurement

magazine for physics
August 1960, Volume 158, Issue 4, pp 417-421 | [Cite as](#)

Measurements without disturbance of the DUT

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Authors and affiliations

Article
Received: 25th February 1959

91

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Citations

Summary

It is shown with the help of thought experiments that indeed measuring processes which have no "negative" measurements consist of an experiment

Interaction-free quantum measurements: A paradox?

American Journal of Physics 49, 925 (1981); <https://doi.org/10.1063/1.10155>

R. H. Dicke

View Affiliations

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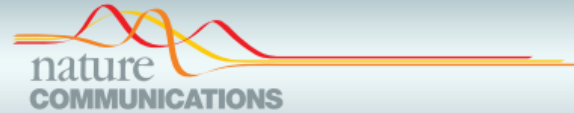
KEYWORDS

- Photon scattering
- Photons
- Particle scattering
- Quantum measurement theory
- Light scattering

ABSTRACT

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In Heisenberg's uncertainty principle, using a microscope to determine the position of a particle makes the particle's momentum uncertain. This is also true for the particle's energy. The particle's energy is also transferred to the particle outside the system.



ARTICLE

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Interaction-free measurements by quantum Zeno stabilization of ultracold atoms

J. Peise¹, B. Lückel¹, J. L. ...

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ABSTRACT

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Interaction-free measurement (IFM) is a quantum process where, in the ideal situation, an object can be detected without any interaction taking place with the probing photon. Here we show that the problem of interaction-free measurement can be regarded as a problem of quantum-channel discrimination. In particular, we look for the optimal photon states that can minimize the detection error and the photon loss in detecting the presence/absence of the object, which is taken to be semi-transparent and the number of the interrogation cycle is assumed to be finite. Finally, we show that minimizing the detection error through the use of entangled photons is possible.

Interaction-free measurement



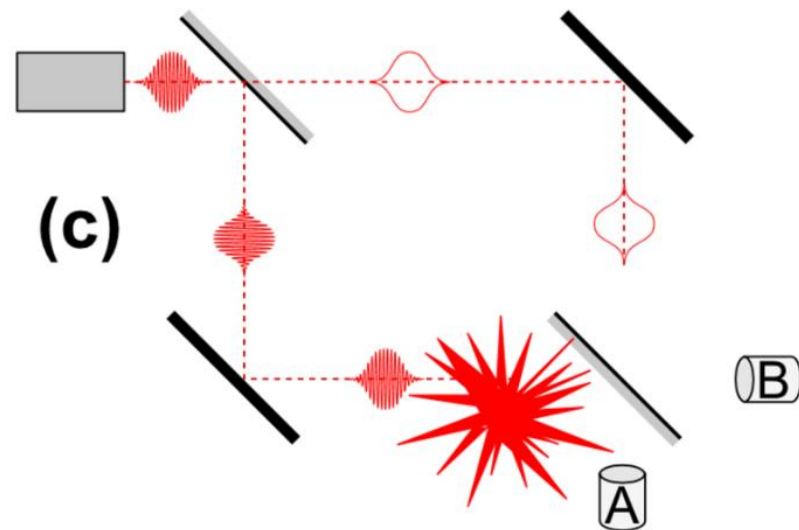
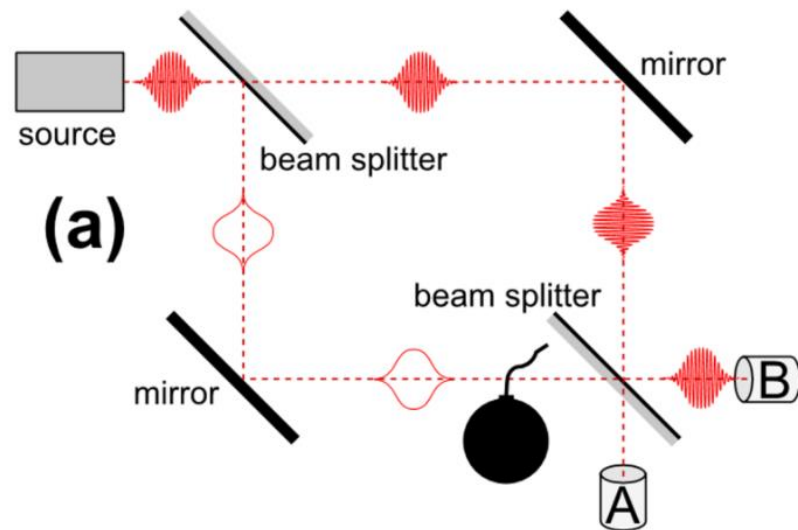
Quantum Mechanical Interaction-Free Measurements

Avshalom C. Elitzur^{1,2} and Lev Vaidman¹

Received August 17, 1992; revised January 2, 1993

A novel manifestation of nonlocality of quantum mechanics is presented. It is shown that it is possible to ascertain the existence of an object in a given region of space without interacting with it. The method might have practical applications for delicate quantum experiments.

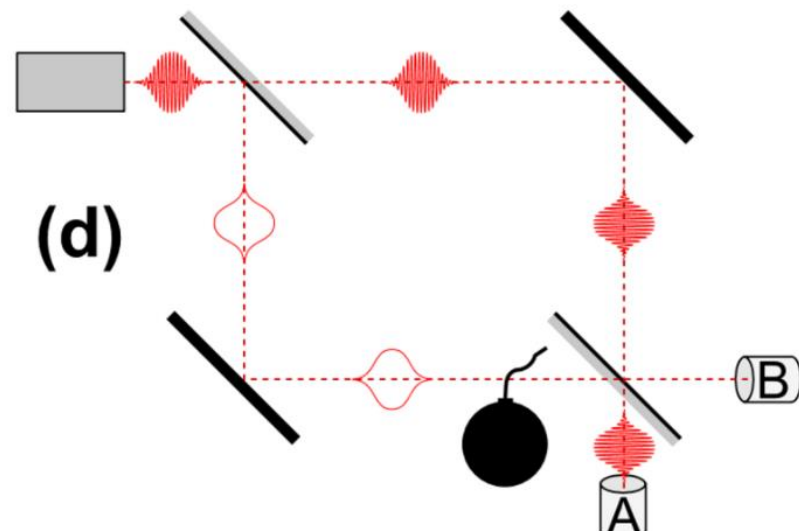
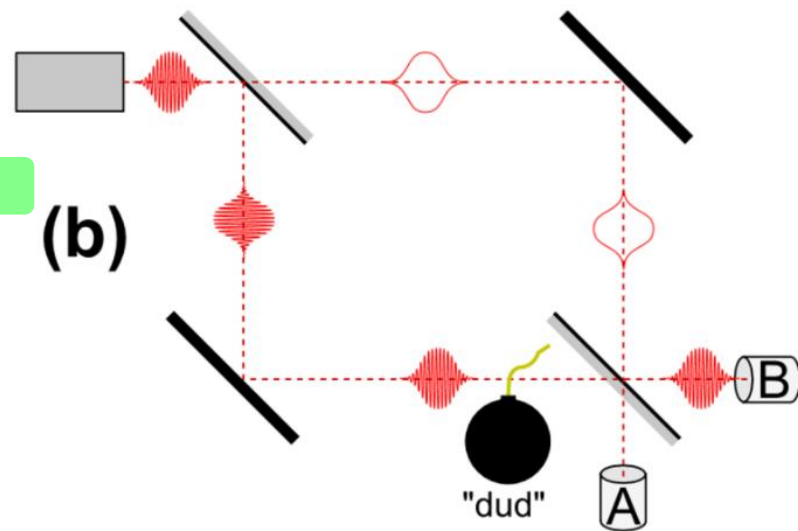
Elitzur-Vaidman thought experiment



a,b No bomb in the setup.

c Bomb explodes.

d Good bomb, No explosion.



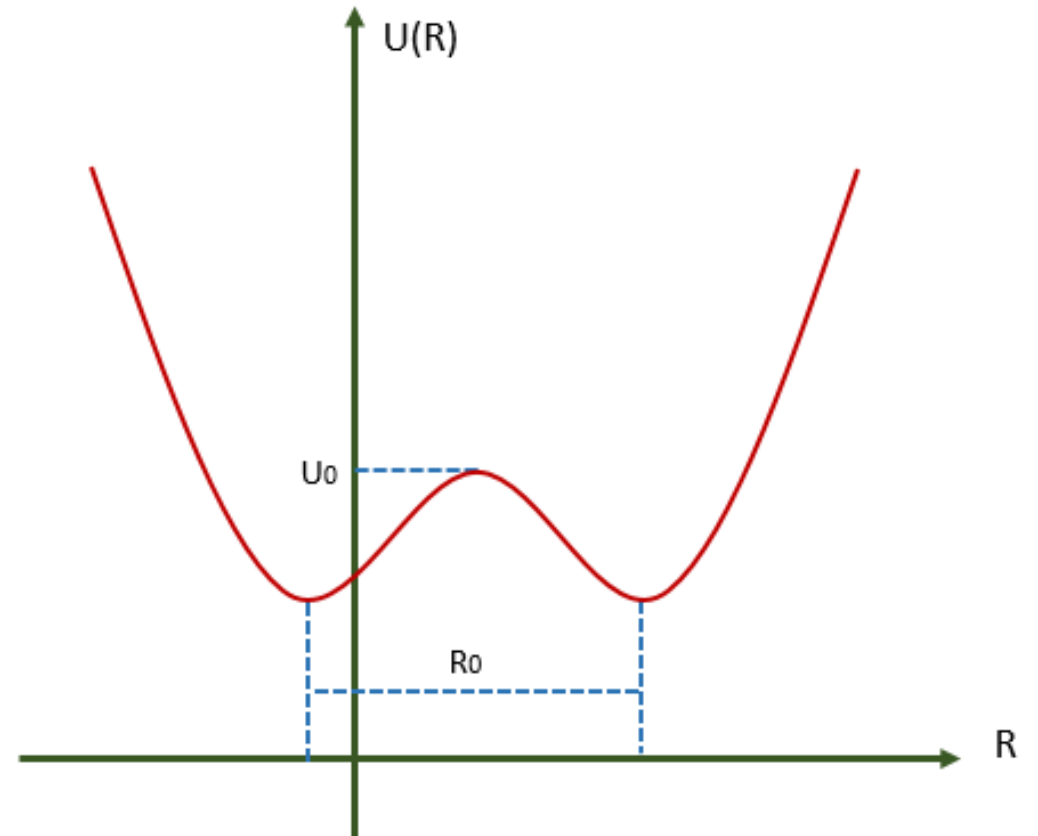
Model

$$H_s = -\frac{\hbar}{2}\Delta(|+\rangle\langle-| + |- \rangle\langle+|)$$

- Δ is a measure of the strength of the tunneling

- New parameter $\hbar = \frac{\hbar}{R_0 P_0} = \frac{\hbar}{U_0 \tau_0}$ is a measure of the macroscopicity of the system

System: double well potential



Environment: a set of harmonic oscillators

$$H_{\varepsilon} = \sum_{\alpha} \left(\frac{1}{2} \hat{p}_{\alpha}^2 + \frac{1}{2} \omega_{\alpha}^2 \hat{x}_{\alpha}^2 - \frac{1}{2} \hbar \omega_{\alpha} \right)$$

frequency of the particle α of environment

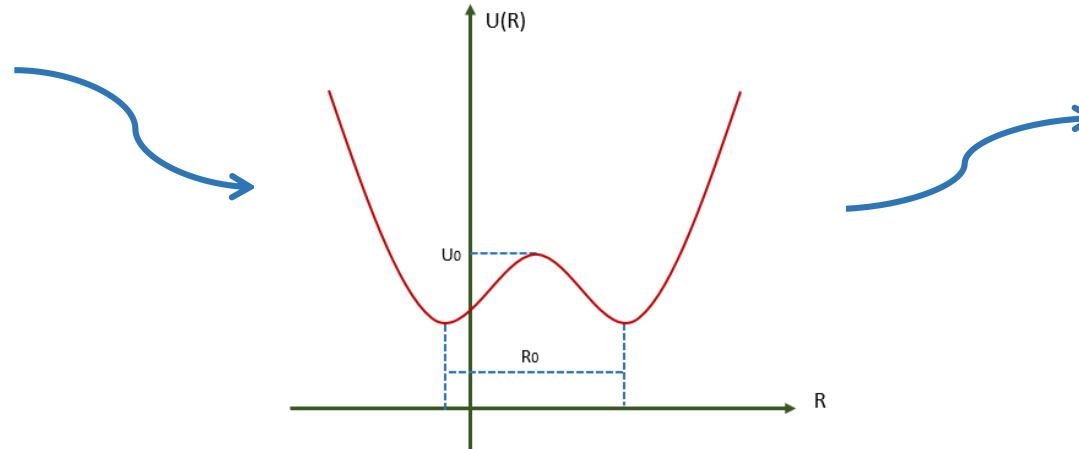
Model

Interaction Hamiltonian:

$$H_{s\varepsilon} = - \sum_{\alpha} (\omega_{\alpha}^2 f_{\alpha}(x) \hat{x}_{\alpha} + \frac{1}{2} \omega_{\alpha}^2 f_{\alpha}^2)$$

Environment oscillator α is displaced by $f_{\alpha}(x)$

Environment



Perturbation

Thought Experiment

We use operators

$$\left\{ \begin{array}{l} |-\rangle \xrightarrow{S_1 \text{ or } S_2} (A|-\rangle + iB|+\rangle) \\ |+\rangle \xrightarrow{S_1 \text{ or } S_2} (A|+\rangle + iB|-\rangle) \end{array} \right.$$

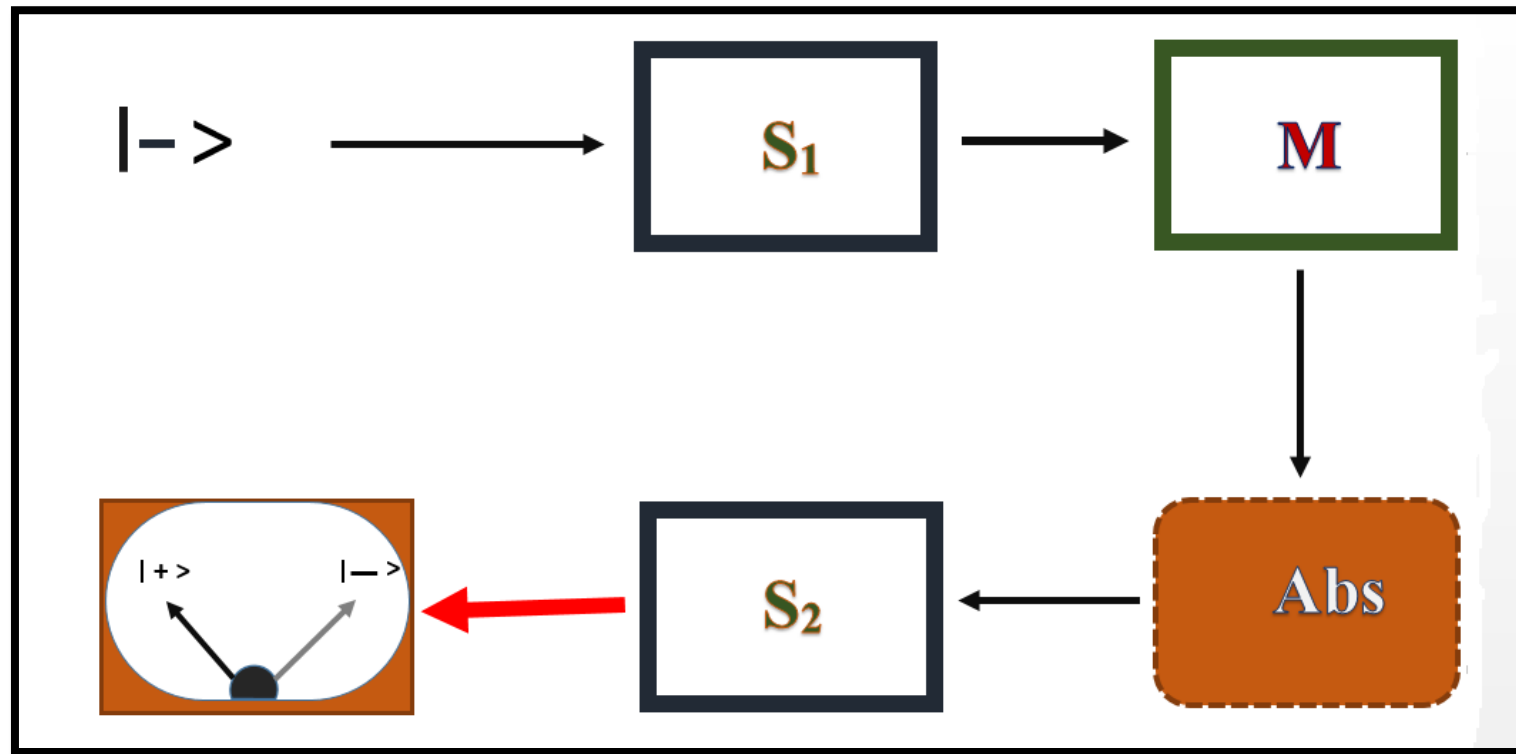
$$|-\rangle \xrightarrow{M} i|+\rangle$$

$$|+\rangle \xrightarrow{M} i|-\rangle$$

There is an absorber of state $|-\rangle$ in the setup
(Abs)

Thought Experiment

The state $|-\rangle$ first experiences operator S_1 and then M . Then, if there were an object the state $|-\rangle$ would be absorbed and finally, the resulting state would encounter S_2 . After S_2 we let the environment interact with the system. At the end, the Final state would be detected by detectors



Thought Experiment

No Environment,
No Abs.

Only D_- clicks

The environment
effects on the
system

$$\begin{cases} P_{-}^{\varepsilon}(t) = \frac{1}{2}(1 + e^{-\Gamma t/2} \cos \Omega t) \\ P_{+}^{\varepsilon} = \frac{1}{2}(1 - e^{-\Gamma t/2} \cos \Omega t) \end{cases}$$

Γ^{-1} is the life time of the shifted energy $E_1 + \delta E_1$.

$$\Omega = (\delta E_1 - \delta E_0)/h$$

The environment
effects on the system
and Abs. is present in
the setup.

$$\begin{cases} P_{-}^{Abs,\varepsilon} = A^4 \left\{ \frac{1}{2} + \frac{1}{2} e^{-\Gamma t/2} \cos \Omega t \right\} + A^2 B^2 \left\{ \frac{1}{2} - \frac{1}{2} e^{-\Gamma t/2} \cos \Omega t \right\} \\ P_{+}^{Abs,\varepsilon} = A^4 \left\{ \frac{1}{2} - \frac{1}{2} e^{-\Gamma t/2} \cos \Omega t \right\} + A^2 B^2 \left\{ \frac{1}{2} + \frac{1}{2} e^{-\Gamma t/2} \cos \Omega t \right\} \end{cases}$$

Results & Discussion

The true contribution of free-measurement
in $P_+^{Abs,\varepsilon}$ is not obvious

$$\left\{ \begin{array}{l} P_+^{Abs} = P_+^{Abs,\varepsilon} - P_+^{Abs,\varepsilon} P_+^\varepsilon \\ \quad = \frac{1}{4} - \frac{1}{4} P_+^\varepsilon \\ \text{We used } P_+^{Abs,\varepsilon} = \frac{1}{4} \text{ for } A = B = \frac{1}{\sqrt{2}} \end{array} \right.$$

It holds always true



It is logically possible to have
free-measurement

when $P_+^\varepsilon \rightarrow 0, P_+^{Abs,\varepsilon} \rightarrow \frac{1}{4}$



It is possible to see
interaction-free measurement
for 25% of detections

Results & Discussion

For an isolated system $\Gamma \rightarrow 0$

$$\begin{aligned} P_+^{Abs,\varepsilon} &\rightarrow A^4 \sin^2 \Omega t / 2 + A^2 B^2 \cos^2 \Omega t / 2 \\ P_-^{Abs,\varepsilon} &\rightarrow A^2 B^2 \sin^2 \Omega t / 2 + A^4 \cos^2 \Omega t / 2 \end{aligned}$$

Elitzur-Vaidman results

For a fully decohered system we have $\Gamma \gg 1$, $Q = e^{-\Gamma t/2} \cos \Omega t \rightarrow 0$

$$P_+^\varepsilon \rightarrow \frac{1}{2}, P_+^{Abs} = \frac{1}{8}$$

Free-measurement could be imagined principally

For a macroscopic quantum system $\hbar = 0.1$

$$Q \rightarrow 1, P_+^\varepsilon \rightarrow 0$$

All the detections at D_- refer to free-measurement

Conclusion

The dissipative effects of environment cause some detections at D_-

It is possible to distinguish between the effects of environment and interaction-free measurement.

For a macroscopic quantum system in interaction with the environment, it is possible to see interaction-free measurement.

Is it possible to describe a physical reality without direct measurement?

Thank you

