sipation theorem of 1951.[8] They showed that the two phenomena are inextricably linked—that the existence of one requires the existence of the other. Much later Jay R. Ackerhalt and coworkers,[9] Israel R. Senitzky[10] and Peter W. Milonni and coworkers[11]—while working totally within the context of standard QED—were able to show that spontaneous emission can be interpreted as arising from vacuum fluctuations or from radiation reaction, dependent entirely on how the ordering of the field operators is chosen. By an appropriate choice, *any* linear combination of the two effects can be achieved. In 1982 J. Dalibard, J. Dupont-Roc and Claude Cohen-Tannoudji argued that the correct linear combination is $\frac{1}{2}$(vacuum fluctuation) and $\frac{1}{2}$(radiation reaction) to make the free-field operators and source-field operators separately Hermitian.[12]

Perhaps the point is that if one wants to observe the vacuum fluctuations one must use a charged particle—in which case the particle's self-field contributes to the measurement. In contradistinction, one can never observe the self-field of a charge in the absence of the all-permeating zero-point fluctuations. Any separation of these two effects can take place only in our minds, and then it's philosophy—not physics.

References

1. P. A. M. Dirac, Proc. R. Soc. London, Ser. A **114**, 243 (1927).
2. E. Fermi, Rend. Lincei. **5**, 795 (1927).
3. H. B. G. Casimir, Proc. Kon. Akad. Ned. Wet. **51**, 793 (1948).
4. L. D. Landau, E. M. Lifshitz, *Electrodynamics of Continuous Media*, Pergamon, Oxford (1960), p. 368.
5. J. Schwinger, L. L. De Raad Jr, K. A. Milton, Ann. Phys. (NY) **136**, 229 (1981).
6. A. O. Barut, J. Kraus, Found. Phys. **13**, 189 (1983). A. O. Barut, J. F. van Huele, Phys. Rev. A **32**, 3187 (1985).
7. A. O. Barut, J. P. Dowling, submitted to Phys. Rev. A.
8. H. B. Callen, T. A. Welton, Phys. Rev. **83**, 34 (1951).
9. J. R. Ackerhalt, P. L. Knight, J. H. Eberly, Phys. Rev. Lett. **30**, 456 (1973).
10. I. R. Senitzky, Phys. Rev. Lett. **31**, 955 (1973).
11. P. W. Milonni, J. R. Ackerhalt, W. A. Smith, Phys. Rev. Lett. **31**, 958 (1973).
12. J. Dalibard, J. Dupont-Roc, C. Cohen-Tannoudjii, J. Phys. (Paris) **43**, 1617 (1982).

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2/87

SPRUCH REPLIES: It has long been clear (see the literature cited by Jonathan P. Dowling) that the concept of electromagnetic vacuum fluctuations is not the only viewpoint one can adopt in explaining retarded interactions. However, space limitations—my article was rather long as it was—prevented me from discussing an alternative view based on radiation reactions. That was much to my regret, since each viewpoint brings its own insights, insights that are particularly valuable now that Casimir effects are no longer restricted to atomic phenomena, having recently become of great interest in a number of other areas of physics. I am therefore delighted to have this latter point of view not only presented but presented so well.

I do have a slight objection to the last sentence of the letter. Though the author in no way implies any such thing, one could conceivably come away with the impression that I am philosophically oriented.

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7/87

Peer review and the FEL

The news story on the Strategic Defense Initiative in the January 1987 issue (page 47) presents a useful survey of current thinking in and out of government. One point in particular, however, is worth examining in more detail, namely that "the centerpiece of the program is the free-electron laser."

While there has been considerable discussion in PHYSICS TODAY about the desirability of the proposed Superconducting Super Collider in the light of severe budget constraints, similar scientific and public attention has not been focused on such expensive defense-related projects as the proposed multimile-long FEL facility for which site selection is under way.[1] It is anticipated that this project will cost on the order of $3 billion.

The lack of peer review in the SDI Organization makes this demonstration program suspect. Independent of the very persuasive political, strategic and purely technological arguments against Star Wars, the decision to go ahead with a giant FEL facility is questionable.

The leading contenders for the prototype FEL space weapon are a Los Alamos group[2] and a Lawrence Livermore Lab facility.[3] The former uses an rf linac to inject very short electron beam pulses into an optical cavity containing a wiggler magnetic field. Published results for the coherent output radiation show that the efficiency

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is quite low, below 10%. Furthermore, one sees beam instabilities at these energies; these produce sidebands and damaging harmonics. The energies are below what is required for operation in the visible, and thus the instabilities can be anticipated to be worse in a scaled-up version. In proposing to scale up the system to shorter wavelengths and higher efficiencies, as well as increasing the average power by many orders of magnitude, the proponents are going against a predictable trend toward lower gain and efficiency at higher beam energies. The existing beam quality, or the emissivity and brightness, of rf linacs, as well as their current and duty cycle, are each one or two orders of magnitude away from the requirements.

The Livermore version is based on high-current induction linacs that inject relatively long and infrequent beam pulses into an active "tapered wiggler" region, where the system produces an amplified coherent electromagnetic emission. Here remarkably high efficiency, 30–40%, has been achieved. But the radiation is in the microwave region and the duty cycle is so low that the average output power is on the order of a few hundred watts. To expect to scale up this kind of system with high-current injectors that operate at kilohertz pulse rates, with induction-loop elements that cycle at the same rate, and to do all this without producing many kinds of beam and accelerator instabilities is insupportable optimism.

As with much of the "innovative technology" being supported by the SDI Organization, there is little relation between the public relations and the actual technological achievements. It is very unlikely that one could scale up either design by the many necessary orders of magnitude within a few years without encountering insurmountable difficulties, or ones prohibitively expensive to overcome. Even if producing a prototype were possible, the specifications for a complete system of hundreds of these facilities and their companion orbiting mirrors would make the expense and the power requirements astronomical.

References

1. SDI Monitor **1**, 284 (1 December 1986).
2. B. E. Newman *et al.*, IEEE J. Quantum Electron. **QE-21**, 867 (1985).
3. T. J. Orzechowksi *et al.*, Phys. Rev. Lett. **57**, 2172 (1986).

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THE SDIO DEPUTY FOR TECHNOLOGY REPLIES: The free-electron laser program directed by the Strategic Defense Initiative Organization and managed by the US Army Strategic Defense Command is a complex and evolving program. It is therefore understandable that Gary R. Goldstein has expressed a number of reservations in his letter.

The current phase of the FEL program is designed to validate those technologies critical to the concept of a ground-based laser system. Such a system would also require space-based mirrors to relay the beam to distant targets for boost-phase intercept or midcourse interactive discrimination. The relay mirror platforms are being addressed in separate technology development efforts. While the FEL program may accurately be described as the "centerpiece" of the directed-energy program, the GBL system is but one layer of a multitiered defensive architecture and in fact is not expected to be included in a first-phase deployment. The more mature kinetic-energy interceptors would play the lead role in such an initial system.

The critical technical issues related to the scaling of free-electron lasers to high power and shorter wavelengths with acceptable efficiencies are being investigated in our current program. In addition, we are studying the critical technical issues related to the efficient propagation of a high-power laser beam through the atmosphere.

Prior to final commitment to any large-scale FEL integration at White Sands Missile Range, our office will conduct a thorough review, with recognized experts in accelerator, laser and propagation technology, to determine whether there is sufficient confidence to proceed into the next phase. Each of the FEL device teams is conducting a number of intermediate design-validation and risk-reduction experiments to address power and efficiency scaling in a quantitative way. The release of funds for the large-scale demonstration (considerably less than the $3 billion cited by Goldstein) is directly related to the successful completion of these intermediate milestones.

Contrary to Goldstein's assertion, the FEL program has been subjected to extensive peer review. All aspects of the laser device and atmospheric propagation physics have been independently analyzed and assessed by a variety of Jason groups during their past three summer studies.

The FEL program was thoroughly reviewed at the classified level by a team of national experts headed by George Dacey (former director of Sandia National Laboratories) during the spring of 1986. In addition, the Army, our executing agent, is establishing a technical advisory group to be headed by Lieutenant Colonel Tom Johnson, director of research for the US Military Academy, West Point. Johnson's committee includes members of the academic and government communities who are prominent in FEL, accelerator and atmospheric physics. This group will conduct periodic, exhaustive reviews of the FEL device technology programs to ensure that all critical technical issues are being adequately addressed and that the selection of a device technology for scale-up will result in a minimum-risk program.

Of course, there are certain technical and integration issues that cannot be resolved simply by analysis or subscale laboratory experiments. It is the resolution of these issues that ultimately requires the investment in a large-scale test facility. Clearly, it is essential that technical issues such as these be resolved before any informed decision regarding the long-term efficacy of strategic defenses is made. We in the SDI Organization are taking every measure possible to minimize the risks associated with our research program and welcome all responsible technical critiques.

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Maria Mayer: The war years

While Karen E. Johnson was working on her doctoral thesis, *Maria Goeppert Mayer and the Development of the Nuclear Shell Model*,[1] she interviewed me on 20 July 1984. I took the opportunity to make available to this student of the history of science material concerning Mayer, particularly pertaining to our collaboration during the war and its subsequent publication.[2,3] During that interview I emphasized how Mayer's background in matrix mechanics, her ability to assemble and classify large bodies of data and her work on spin–orbit coupling in the atomic spectra of heavy atoms provided an ideal background and preparation for the development of the nuclear shell model.

Although Johnson acknowledges my assistance both in her thesis and in her PHYSICS TODAY article (September 1986, page 44), she did not give me the opportunity to review either of those works for comment prior to their submission to the relevant media. In this letter I call attention to factual errors in the PHYSICS TODAY article. A more complete statement of where I differ from Johnson's description of Mayer's