case $\phi(z) = z^{-1} + z^{-3}$ and (6) becomes

$$\omega^4 - (\omega_p^2 + k^2)\,\omega^2 - u_0^2\,\omega_p^2\,k^2 = 0. \qquad (9)$$

The same approximation would have been obtained (in the limit $u_3k/\omega \ll 1$) for an arbitrary f_0, as may be seen by expanding the denominator of (4) in powers of v_3. The four solutions of (9) are

$$\omega = \pm\{\tfrac{1}{2}[\omega_p^2 + k^2 \pm ((\omega_p^2 + k^2)^2 + 4u_0^2\,\omega_p^2\,k^2)^{1/2}]\}^{1/2}$$

The solution ω_4, obtained by taking minus signs in both choices, is negative imaginary, showing the existence and rate of growth of self-excited waves. This solution is valid only when $u_3k/\omega \ll 1$ which implies $u_0 \gg u_3$, as becomes evident from the approximate expression

$$\omega_4 \cong -\,i u_0\,\omega_p k/(\omega_p^2 + k^2)^{1/2}.$$

A more detailed study of (6) shows that for large values of k one obtains damped waves.

The author is indebted to Dr. B. D. Fried for many valuable discussions of these matters.

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SOLID STATE INFRARED QUANTUM COUNTERS*

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Since maser operation is based on stimulated emission of radiation, masers have an inherent limiting noise temperature of $h\nu/k$ due to spontaneous emission.[1,2] Weber[2] has called attention to the fact that it is possible to construct quantum-mechanical amplifiers without spontaneous emission noise. In fact, this is the usual state of affairs for x-ray or γ-counters. This note describes how a solid counter for infrared or millimeter wave quanta might be constructed in principle.

Consider a crystal containing ions which, among others, have the energy levels shown in Fig. 1. Salts of the rare earths and other transition group ions, which may be embedded as impurities in host lattices, offer examples of this situation.[3,4] The distance between the ground level and level E_2 is such that $h\nu_{12} \gg kT$. If, for example, $h\nu_{12} \sim 100$ cm^{-1} and $T \sim 2°$K, only the ground state is populated. Intense light at the optical frequency ν_{23} is not absorbed, because level E_2 is empty. Whenever an incident infrared quantum $h\nu_{12}$ is absorbed, the light will induce a second transition to E_3, provided its intensity produces transitions at a faster rate than the radiationless decay or spontaneous emission from level E_2 back to the ground state.

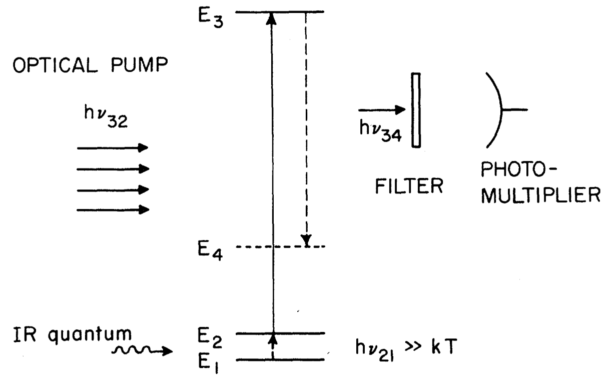

FIG. 1. Infrared quantum counter. Several ions of transition group elements have appropriate energy level diagrams: $h\nu_{21} = 1 - 5000$ cm^{-1}, $h\nu_{32} = 10^4 - 5\times 10^4$ cm^{-1}.

Spontaneous emission from E_3 to E_2 will produce resonance radiation. The system will be repumped, and several quanta $h\nu_{32}$ may be re-emitted for each incident quantum $h\nu_{21}$. It will be difficult to detect these quanta $h\nu_{32}$ in the presence of the intense pumping flux, although one may use discrimination in polarization and direction of propagation. When radiation due to spontaneous emission from level E_3 to E_1 is able to leave the crystal, quanta $h\nu_{31}$ may be counted directly. If this radiation is self-absorbed, a fourth level will provide an effective discrimination in frequency. The fluorescent quanta $h\nu_{34}$ may be counted with a photomultiplier and a suitable filter.

A variation of this scheme is that E_1 is an occupied deep impurity level, E_2 is an empty impurity level, and E_3 represents the conduction band. The incident quantum $h\nu_{21}$ triggers a photoconductive avalanche in the semiconductor near absolute zero of temperature.

It is illuminating to point out the relationship with optical pumping methods proposed by

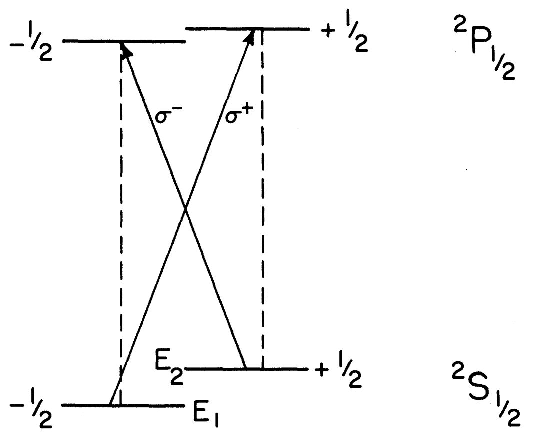

FIG. 2. Optical pumping between $^2S_{1/2}$ and $^2P_{1/2}$ doublets (reference 5). σ^+ pumping produces a maser at $h\nu_{21}$, the ground-state splitting. σ^- pumping produces a quantum counter at $h\nu_{21}$.

Kastler[5] and with three-level masers.[6,7] Consider the σ^- and σ^+ transitions between the $^2S_{1/2}$ and $^2P_{1/2}$ states shown in Fig. 2. It makes no difference whether these transitions are separated by the sense of circular polarization[5] or by the Zeeman frequency splitting.[8] If the σ^+ transition is pumped, one obtains maser action in the ground-state doublet. If the σ^- transition is pumped, one prepares a quantum counter. To eliminate thermal noise in this counter and keep all particles in the ground state E_1, either free atoms in a beam or a crystal near absolute zero of temperature should be used.

The condition on the intensity for optical pumping is the same to achieve maser action or quantum counting. Using the parlance of magnetic resonance, one has to approach saturation of the optical absorption coefficient at the pumping frequency. The optically induced transitions must have a faster rate than the competing relaxation mechanisms between levels E_2 and E_1. In favorable cases it appears possible to produce the required optical intensities.

For the quantum counter, details of the decay from level E_3 are not important, provided radiationless transitions are not dominant. For the maser action, one requires a decay to level E_2 at the faster rate than the relaxation rate from E_2 to E_1. It is evident that in either case more than one optical transition may be pumped.

Although the prospect of reaching a quantum efficiency of 100% or even 10% appears remote, the type of infrared detector proposed here may be useful even if it falls short by many orders of magnitude of its ultimate potential.

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EXTENDED FINE STRUCTURE OF K X-RAY ABSORPTION EDGES IN PERMINVAR

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In other communications,[1-3] the structural origin and mechanism of the magnetic annealing of soft, magnetic alloys have been investigated. It has been found that the ability of soft, magnetic alloys containing Fe, Co, and Ni to exhibit magnetic annealing properties is due to oxygen present as an impurity. Single crystals with an oxygen content of 0.001-0.002% respond to field heat treatment. Single crystals with an oxygen content of 0.0001% fail to respond to field heat treatment.

It is well known that x-ray spectra, both in emission and absorption, are sensitive to the state of chemical combination of the elements under study. Thus there is a possibility that a study of the x-ray spectra of Fe, Co, and Ni in soft, magnetic alloys might yield information on how the metal atoms are associated with the oxygen impurity.

The extended fine structure of the K x-ray ab-