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Informal Report

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Bibliography of GRASER Research

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NOTICE

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BIBLIOGRAPHY OF GRASER RESEARCH

by

G. C. Baldwin

ABSTRACT

A bibliography of all available literature on the problem of developing gamma-ray lasers or of observing stimulated emission or coherent spontaneous emission of nuclear gamma radiation, together with a number of references that deal with phenomena that are expected to be central to their realization.

PREFACE

This compilation includes all publications we have been able to find, together with a few significant private communications and proposals, that deal directly with the problem of stimulated, amplified, or coherent spontaneous emission of gamma radiation from nuclear isomers. It also includes a limited selection of peripheral references that deal with phenomena essential to understanding of the gain requirements, kinetics, linebreadth, pumping, photon removal, and resonator questions.

It is noteworthy that by far the majority of the cited graser[#] papers are essentially proposals, or reviews of other proposals! Nevertheless, it is felt that this should be a complete compilation, if it is to give a true perspective of the subject. It should indicate not merely the directions future research might best pursue, but those it might best avoid!

The format, except for the abstracts and comments, is that specified by the Reviews of Modern Physics, for whom an article is now in preparation with J. C. Solem of Los Alamos Scientific Laboratory, V. I. Gol'danskii and Yuri Kagan of the USSR Academy of Sciences as co-authors. For those interested in more precise dates of original publication, months of publication are included for the years 1961-63.

Papers directly concerned with the graser problem or with the closely related topic of nuclear superradiance are identified with an asterisk (*) in order to distinguish them from those dealing with peripheral material. It is believed that the former list is essentially complete; the latter, of course, includes only the minimum number of references considered necessary for treating the problems of linebreadth, pumping reactions, etc., that are inevitably associated with the graser problem.

I wish to thank Prof. Gol'danskii for sending me copies of his papers and of several bibliographies on this subject that were prepared in the USSR, as well as the issue of Nauka e Zhyzn ("Science and Life") referred to as "Svoren (1975)"; George Krycuk (Rensselaer Polytechnic Institute) and Helen Dahlby for translations of several Soviet papers not promptly available in translated form; Carol Malmstrom for assistance with the RECON literature search; Pita Valencia for organizing and composing the final text; and G. A. Keyworth and J. C. Solem for encouragement of this research. The support of the Department of Energy is gratefully acknowledged.

[#] Several acronyms have been proposed to designate devices that might make use either of stimulated nuclear transitions or of coherent spontaneous emission of gamma rays; namely, GRASER, NASIR and GASER. The first appeared in the open literature in 1963, the second only in a classified study, and the third in 1973; we recommend the term GRASER, as it has been the most widely used, and its connotation is more obvious. GAMMA LASER is too cumbersome. We do not expect confusion with devices for generating gravitons in the near future!

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FIGURE 2. Chronology of papers and identifiable reports cited that deal with coherent emission of gamma radiation.

BIBLIOGRAPHY

1917

Einstein, A., Physik Zeitschr. 18, 121-128.
 "On the Quantum Theory of Radiation"

SUMMARY: It is shown that the Planck distribution law for thermal radiation, the Maxwell-Boltzmann distribution of molecular velocities and the Boltzmann canonical distribution of excited state populations are consistent, provided one postulates that an atomic system can be induced to radiate, as well as to absorb, radiation of the same frequency that it can emit spontaneously. The ratio of the coefficient for spontaneous to that for induced emission is shown to be proportional to the third power of the frequency. The momentum of the induced radiation is shown to have the same direction as that of the inducing radiation.

1939

Lamb, W. E. Jr., Phys. Rev. 55, 190-197.
 "Capture of Neutrons by Atoms in a Crystal"

ABSTRACT: The precise determination of the properties of nuclear resonance levels from the capture of slow neutrons is made difficult by the fact that most of the substances used for absorbers and detectors are in the solid state, so that the calculations of Bethe and Placzek for the influence of the Doppler effect are inapplicable, since these were based on the assumption of a perfect gas. In this paper, their calculations are generalized to include the effect of the lattice binding. Under the assumption that the crystal may be treated as a Debye continuum, it is shown that for sufficiently weak lattice binding, the absorption curve has the same form as it would in a gas, not at the temperature T of the crystal, however, but at a temperature which corresponds to the average energy per vibrational degree of freedom on the lattice (including zero-point energy). In cases of somewhat stronger lattice binding, the line form is found to be more complicated, and may even have a fine structure. Plots are given of the absorption line in several typical cases. An approximate formula for the cross section for self-indication is also derived.

1946

Brillouin, L., "Wave Propagation in Periodic Structures," McGraw Hill, reprinted 1953, 254 pp., Dover Publications, New York

SUMMARY: A unified treatment of the propagation of mechanical, electromagnetic, etc. waves in one-, two- and three-dimensional periodic structures, including crystal lattices and electric transmission lines.

1953

Dicke, R. H., Phys. Rev. 89, 472-473.

"The Effect of Collisions upon the Doppler Width of Spectral Lines"

ABSTRACT: Quantum mechanically the Doppler effect results from the recoil momentum changing the translational energy of the radiating atom. The assumption that the recoil momentum is given to the radiating atom is shown to be incorrect if collisions are taking place. If the collisions do not cause broadening by affecting the internal state of the radiator, they result in a substantial narrowing of the Doppler broadened line.

1954

Dicke, R. H., Phys. Rev. 93, 99-110.

"Coherence in Spontaneous Radiation Processes"

ABSTRACT: By considering a radiating gas as a single quantum-mechanical system, energy levels corresponding to certain correlations between individual molecules are described. Spontaneous emission of radiation in a transition between two such levels leads to the emission of coherent radiation. The discussion is limited first to a gas of dimension small compared with a wavelength. Spontaneous radiation rates and natural line breadths are calculated. For a gas of large extent, the effect of photon recoil momentum on coherence is calculated. The effect of a radiation pulse in exciting "super-radiant" states is discussed. The angular correlation between successive photons spontaneously emitted by a gas initially in thermal equilibrium is calculated.

1958

- * Schawlow, A.L., and C. H. Townes, Phys. Rev. 112, 1940-1949.
"Infrared and Optical Masers"

ABSTRACT: The extension of maser techniques to the infrared and optical region is considered. It is shown that by using a resonant cavity of centimeter dimensions, having many resonant modes, maser oscillation at these wavelengths can be achieved by pumping with reasonable amounts of incoherent light. For wavelengths much shorter than those of the ultraviolet region, maser-type amplification appears to be quite impractical. Although use of a multimode cavity is suggested, a single mode may be selected by making only the end walls slightly reflecting, and defining a suitably small angular aperture. Then extremely monochromatic and coherent light is produced. The design principles are illustrated by reference to a system using potassium vapor.

Mössbauer, R. L., Zeits. f. Physik 151, 124-143.

"Nuclear Resonance Fluorescence of Gamma Radiation in ^{191}Ir "

ABSTRACT: The resonance absorption of 129-keV gamma radiation in ^{191}Ir in the nuclear decay of ^{191}Os was investigated. The cross section for resonant absorption was measured as a function of the temperatures of source and absorber in the range $90\text{K} < T < 370\text{K}$. The lifetime τ of the 129-keV level in ^{191}Ir is found to be 3.6×10^{-10} s. The absorption cross section exhibits, with lowering temperature, a strong increase as a consequence of crystal binding in the absorber and source materials. The theory of Lamb on the resonance absorption of slow neutrons in crystals was applied to the resonance absorption of gamma radiation. At low temperatures this predicts a strong dependence of the cross section for nuclear absorption on the frequency spectrum of lattice vibrations in solids.

1960

Abragam, A., Comp. Rendus Acad. Sci. 250, 4334-4336.

"Influence of Ultrasonic Phonons on Emission and Absorption of Recoilless Gamma Radiation"

ABSTRACT: We show that introduction of ultrasonic phonons into a crystal containing radioactive nuclei leads to frequency modulation of their γ spectra.

Josephson, B.D., Phys. Rev. Lett. 4, 341.

"Temperature-Dependent Shift of Gamma rays Emitted by a Solid"

COMMENT: It is shown that the energy of recoilless gamma rays is temperature-dependent because the mass change of the emitter affects the lattice vibrations.

Lipkin, H.J., Ann. Phys. 9, 332-339.

"Some Simple Features of the Mössbauer Effect"

ABSTRACT: A simple description is given of the change in the state of a crystal lattice upon emission or absorption of a nuclear gamma ray. A sum rule is derived for the average energy transfer to the lattice. The probability of zero energy transfer is calculated. The results are general and do not assume a particular model for the crystal. Conclusions are presented as simple principles which may be useful as a guide to experimentalists.

Lynch, F. J., R. E. Holland and M. Hammermesh, Phys. Rev. 120, 513-520.

"Time Dependence of Resonantly Filtered Gamma Rays from Fe^{57} "

ABSTRACT: The time dependence of gamma rays emitted by the 14.4-keV state of Fe^{57} has been studied by delayed-coincidence measurements between a 123-keV gamma ray preceding formation of

the state and the 14.4-keV gamma ray from the state. When no filter was used, the number of gamma rays decreased exponentially with the known half-life of 0.1 μ sec. When a foil of Fe^{57} (which was resonant to 14.4-keV radiation) was used as a filter, the number of gamma rays observed through the filter did not decrease exponentially. Instead, the filter absorbed almost none of the gamma rays first emitted by the 14.4-keV state; at later times the absorption increased. Data were taken with three different thicknesses of absorber and with emission and absorption peaks separated by 0 to 11 times the width of the resonance. The energy separation resulted from the Doppler shift associated with a constant velocity between source and absorber. These data were, for the most part, in good accord with the prediction of a theory based on a classical model for absorber and source. In particular, the results verified the theoretical prediction that at certain times the intensity of radiation observed would be greater with the filter than without it.

Podgoretskii, M. I., and I. I. Roizen, *ZhETF* 39, 1473-1475; *Sov. Phys.-JETP* 12, 1023-1024.

"Concerning the Radiation of a Nucleus in the Presence of Unexcited Nuclei of the Same Type"

ABSTRACT: If the emission of a γ -quantum by an excited nucleus takes place in the presence of one or several nuclei of the same type, it becomes possible for the γ -quantum to wander inside the system. In many cases this may lead to a change in the observed frequency and a damping of the radiation, which is direction dependent.

Ruby, S., and D. I. Bolef, *Phys. Rev. Lett.* 5, 5-7.
"Acoustically Modulated γ Rays from Fe-^{57} "

SUMMARY: FM sidebands are shown to be generated when a Mössbauer source is vibrated by a piezoelectric transducer.

Visscher, W. M., *Ann. Phys.* 9, 194-210
"Study of Lattice Vibrations by Resonance Absorption of Nuclear Gamma Rays"

ABSTRACT: It has recently been demonstrated by Mössbauer that in a large proportion of emissions or absorptions of gamma rays by nuclei bound in crystals at low temperature the recoil energy is taken up by the crystal as a whole (no phonons are emitted). This makes it possible to observe resonance absorption of nuclear gamma-rays without high-speed rotors or elevated temperatures, as had been done in the past. In the present paper we show that an extension of Mössbauer's technique can be utilized to directly observe the frequency distribution of lattice vibrations in the crystal. Specifically, if the emitter and absorber have the same favorable crystal structure, then the self-absorption is proportional to $N(S)$, where $N(S)$ dS is the number of phonon

states in an energy interval dS , and S is the Doppler shift in the gamma-ray energy induced by the rotor motion. Criteria are given for determining favorable cases.

1961

- * Rivlin, L., USSR Patent Disclosures #709714, dated January 1961; #710508, dated 1 April 1961.

COMMENT: We have been unable to obtain a copy of this reference, despite its frequent citation in Soviet papers. There is no evidence that the patent was granted, although its citation is clearly intended to base a claim of priority of conception.

1962

- * Baldwin, G. C., J. P. Neissel and L. Tonks, General Electric Co. Report No. 62GL22 (February).
"On the Feasibility of Gamma Ray Amplification by Stimulated Emission of Radiation"

ABSTRACT: It is shown that the cross section for stimulated emission of gamma radiation may exceed that for non-resonant absorption and that population inversion can be achieved in certain isomeric nuclides generated by particle bombardment. A photon-multiplying chain reaction is therefore conceptually possible, but difficult to achieve because of the non-reflectability of gamma radiation and the extreme sharpness of the lines involved. It is nevertheless possible that the critical condition can be satisfied in perfect crystalline solids under stringent environmental conditions; an experimental test is proposed.

- * Baldwin, G. C., C. A. Black, E. E. Goodale, H. Kasch, J. P. Neissel, and J. H. Terhune, General Electric Co. Report No. 62GL176 (December).
"On the Feasibility of Gamma Ray Amplification by Stimulated Emission of Radiation - II"

ABSTRACT: A review is given of the previously reported study by G. C. Baldwin, J. P. Neissel and L. Tonks on the feasibility of a GRASER; i.e., a device employing controlled stimulated emission of gamma radiation. Substances containing high concentration of nuclear isomers can be prepared radiochemically; the central problem then becomes that of the actual γ -ray spectral width resulting from interaction with the nuclear environment. Present theories of gamma ray line widths are reviewed in some detail, and shown to be inapplicable to coherent emission, to the high recoil energy situation in which optical branch excitation should have a dominant role, and to anisotropic, and in particular Bragg angle effects. It is concluded that the question of GRASER feasibility can be answered only by experiment. Some detailed considerations are given of the experiment previously proposed.

Dzyub, I.P., and A. F. Lubchenko, Fiz. Tverd. Tela 3, 2275-2284; Sov. Phys.-Solid State 3, 1651-1657.

"Scattering of γ Quanta by Nuclei of a Solid Body"

ABSTRACT: Resonance and Rayleigh scattering of γ quanta by nuclei of the crystal lattice are examined; the shapes of the excitation spectrum and the scattered γ quantum spectrum have been computed. It is shown that, from spectrum measurements of quanta scattered at the Bragg angle, the frequency spectrum of the normal vibrations of the scattering crystal can be calculated.

Frauenfelder, H., The Mössbauer Effect, 336 pp., W. A. Benjamin, (New York).

COMMENT: A collection of reprints, together with a review of all publications on the subject through August 1961.

1963

- * Babcock, R. V., S. Ruby and L. M. Epstein, Westinghouse Electric Corp. Report WERL-63-927-115-R1 (Dec)
"Stimulated Emission of Gamma Radiation"

ABSTRACT: We find that the rate of stimulated emission of γ -rays cannot exceed 10^{-5} of the spontaneous emission rate. In fact, the characteristics of existing nuclei appear to limit the degree of stimulated emission to less than 1 part in 10^8 . It is possible that stimulated emission in nuclear systems cannot be observed within the foreseeable future, and that further inquiry in this field will be fruitless.

- * Baldwin, G. C., J. P. Neissel, J. H. Terhune, and L. Tonks, Trans. Amer. Nucl. Soc. 6, 178 (June).
"On the Possibility of Maser Action Between Nuclear States"

ABSTRACT: The possibility of a stimulated emission device analogous to the LASER which can generate radiation at gamma-ray wavelengths is examined. Lacking reflectors, its operation would consist of multiplication during single passage of photon avalanches initiated by spontaneous emission. The required high concentration of excited states may be obtainable in many nuclides by radiochemical procedures. The maximum possible resonant cross-section exceeds ordinary absorption by several orders of magnitude. Only a fraction of the resonant cross-section can be effective, because of line-broadening interactions with the nuclear environment. Singular effects in solids (optical branch excitation, localization of lattice disturbance, or Bragg-angle effects) are suggested which may allow operation at recoil-displaced energy without population inversion, as alternatives to the Mössbauer effect. An

experimental technique for directly measuring the stimulated emission cross section by detection of a coherent component in the total radiation is described in some detail. It is concluded that the question of GRASER feasibility can be conclusively answered only by experiments.

- * Baldwin, G. C., J. P. Neissel, and L. Tonks, Proc. IEEE 51, 1247. (September).
"Induced Gamma-Ray Emission"

SUMMARY: Refers to Vali & Vali, discusses similarities and differences between that work and the authors' own study. Notes that (n, γ) reactions with Szilard-Chalmers separation are preferable to beta decay for generating the active nuclear isomers, that recoil shifts may eliminate need for population inversion, but analogies to a nuclear reactor are misleading, that directionality can be achieved by use of elongated (e.g. whisker) crystals, and that the Borrmann effect can be used for developing a resonator. A method of detecting stimulated emission by coincidence counting is proposed. The line broadening effects described by Vali and Vali offer means for external control. (A reply by Vali and Vali is appended).

- * Chirikov, B. V., ZhETF 44, 2016-2022 (June); Sov. Phys.-JETP, 17, 1355-1359 (December).
"The Kinetics of Induced Mössbauer Radiation"

ABSTRACT: We treat the kinetics of induced Mössbauer radiation in an infinite crystal under conditions where the characteristic time of the process is much less than the line width. It is shown that the maximum of the wave will move with a very low velocity, proportional to the line width.

COMMENT: Using first order perturbation theory, it is shown that the cross section for stimulated emission must be time-dependent and that the radiation field therefore develops very slowly: the very pronounced anomalous dispersion, in the case of near-natural line width, makes a resonator unnecessary for a gamma ray laser.

- * Marcuse, D., Proc. IEEE, 51, 849 (May).
"Maser Action Without Population Inversion"

ABSTRACT: The frequency shift associated with photon momentum recoil makes it possible, in principle, to achieve maser action without population inversion. This may enable development of x-ray or γ -ray masers. In particular, it is shown that a positronium maser could be achieved with only 10^{16} atoms cm^{-3} . Bragg reflections are suggested for a resonant cavity.

- * Podolsky, B., J. Mize, and C. Carpenter, AVCO Corp., Technical Documentary Report ASD-TDR-63-543, (August).
"Feasibility Electromagnetic (E-M) Generator Study"

ABSTRACT: The feasibility of the NASIR (nuclear amplification of stimulated isomeric radiation) concept has been examined to some detail. An analysis using up-to-date theories and available data has shown that the feasibility of a nuclear maser cannot be established. The analysis has yielded the following pertinent results: 1) Population inversion using resonant slow neutron capture can be a reality; 2) isomers suitable for initial work in pumping have been established; 3) extra-nuclear effects offer exciting and unapproached avenues for gamma excitation research; 4) a preliminary quantum mechanical model for the probability of extra-nuclear stimulation has been developed; 5) a tentative configuration for a NASIR device is presented, and 6) the importance of the Mössbauer effect in nuclear masers is discussed.

- * Vali, V. and W. Vali, Proc. IEEE 51, 182-184 (January).
"Induced γ -Ray Emission"

SUMMARY: The extension of optical maser techniques to the γ -ray region is considered. It is shown that under certain conditions induced γ rays can be produced. The condition of criticality rather than that of oscillation is used because a γ -ray maser does not have a resonant structure. The main observable effects are the shortening of lifetimes of some γ excitations and the appearance of two or more coherent γ quanta. It appears to be difficult to prepare samples that will become critical. The principles are applied to a specific example.

- Yariv, A. and J. P. Gordon, Proc. IEEE 51, 4-29 (January)
"The Laser"

SUMMARY: This article is a review of the field of optical masers...summarizing both theory and practice. It starts with a theoretical section in which black body radiation theory is used to introduce the concepts of spontaneous and induced transitions. This is followed by derivation of the Schawlow-Townes instability (start-oscillation) condition and a description of different laser media. Other topics treated include: optical pumping, experimental techniques, output power, noise...optical resonators and communications...

1964

- Batterman, B. W. and H. Cole, Rev. Mod. Phys. 36, 681-717.
"Dynamical Diffraction of X-Rays in Perfect Crystals"

SUMMARY" An explanation of the Borrmann effect in terms of the dynamical theory of x-ray diffraction.

Bizina, G. E., A. G. Beda, N. A. Burgov and A. V. Davydov, ZhETF 45, 1408-1413; Sov. Phys.-JETP 18, 973-976.

"Resonance Excitation of An Isomer State in ^{107}Ag with a Mean Lifetime of 63 Seconds,"

ABSTRACT: Resonance excitation of the 93.5-keV isomer state in ^{107}Ag with a mean lifetime of 63 s is realized by means of the Mössbauer effect. Gamma activity induced in a sample of metallic silver as a result of resonance absorption of γ rays from a strong source is observed. The activation was carried out at liquid-helium temperature and low level of acoustic noise. For sources and absorbers heated in vacuum the measured resonance scattering cross section per atom of a natural isotopic mixture is $0.7 \pm 0.2 \times 10^{30} \text{ cm}^2$.

Khizhnyakov, V. V., Fiz. Tverd. Tela 6, 640-641; Sov. Phys.-Solid State 6, 501-503.

"Nuclear Polarizability, Dispersion and Reflection Coefficient Near the Mossbauer Line"

SUMMARY: The complex electric susceptibility of the nucleus for the recoilless line is shown to be comparable with or even to exceed the electronic component of susceptibility, leading to very high values of the index of refraction and reflection coefficient.

Muzikar, C., Czech. Jour. Phys. B14, 211-226.

"Width and Shift of Coherent Spontaneous Radiation Line of a System of Identical Emitters"

ABSTRACT: A study is made of the influence of the retarded electromagnetic interaction of a system of identical oscillators arranged in a cubic lattice on the form of the line of spontaneous radiation...In the long-wave case, it is shown that the line is greatly broadened and shifted...In the optical case...the broadening is of the order of $N(\lambda/a)^2$ and the shift of the order $(\lambda/a)^3$. In the directions satisfying Bragg's condition the line loses its Lorentzian form and further broadening and shifting of the line may occur. It is shown that the vibrations of the crystal lattice influence the coherent effects in the same way as they influence the Mössbauer effect.

Podgoretskii, M. I., ZhETF 45, 780-782; Sov. Phys.-JETP 18, 536-537.
"Resonance Reflection of Gamma Rays from a Crystal Surface"

ABSTRACT: The time dependence of the intensity of resonance rays reflected from a crystal surface is investigated. It is shown that when the resonance frequencies of the radiator and reflector are different the intensity of the reflected γ rays exhibits "beats." The interference between resonant nuclear scattering and Rayleigh scattering by the atomic electrons is treated...

1965

Afanas'ev, A. M. and Yu. Kagan, ZhETF Pis'ma 2, 130-133; Sov. Phys.-JETP Letts. 2, 81.-83.

"Radiation of a System of Excited Nuclei in a Crystal"

SUMMARY: Shows that excited states of nuclei in a crystal can exist for which the decay rate differs greatly from that in a noncoherent system, and that the radiation can be highly anisotropic. Objections are raised to earlier treatments of this problem.

Afanas'ev, A. M. and Y. M. Kagan, ZhETF 48, 327-341; Sov. Phys.-JETP 21, 215-224.

"Suppression of Inelastic Channels in Resonant Nuclear Scattering in Crystals"

ABSTRACT: The resonance scattering of a particle is treated for the case of a crystal containing nuclei with a low lying level. It is shown that, for certain cases, when the Bragg condition is satisfied, a situation may occur where the amplitudes for formation of a compound (excited) state in the incident and diffracted waves are equal in magnitude and opposite in sign. Because of obvious interference of the two waves, in this case the probability for formation of the compound nucleus is zero, and thus the inelastic channel disappears and the crystal becomes nonabsorbing (partially or completely). A special analysis is made of the effect of vibration of the nuclei in the lattice....The problem is studied in detail for the case of resonance scattering of γ quanta in the presence of internal conversion. It is assumed that the γ quanta are produced in the source in a decay accompanied by the Mössbauer effect. It is shown that in an M1 transition, for γ quanta with a particular polarization, the effect described occurs for Bragg scattering from any crystal plane...

- * Baldwin, G. C., J. H. Terhune, and J. H. Bredt, General Electric Co. Report DA-18-035-AMC-35(A) to U.S. Army Nuclear Defense Laboratory. "Nuclear Super-Radiance and Stimulated Emission of Gamma Radiation"

ABSTRACT: A possibility exists that nuclear gamma radiation may be generated by a controllable and directable mechanism analogous to the generation of light beams in an optical maser, with similar properties of coherence. This report examines that possibility. It presents a background of elementary theory to guide further study, identifying the scientific and technical disciplines which must contribute to the development and it pinpoints the central problem as that of the theory of coherent emission of radiation by an extended many-component system. The relevant scientific literature is surveyed. A theory of the emission of nuclear electromagnetic radiation by a solid, partially developed by the authors in an earlier investigation,

is extended and interpreted. The possibility of inducing anomalous radiation rates in certain directions by introduction of coherent mechanical vibrations is considered. It is concluded that although isomeric nuclear material can be prepared, the conditions under which it may emit radiation coherently are not presently attainable with known isomer nuclides. Further research in the Mössbauer effect, in gamma ray optics, in nuclear chemistry and in the theory of emission of radiation are suggested.

- * Terhune, J. H., and G. C. Baldwin, Phys. Rev. Letts. 14, 589-591.
"Nuclear Superradiance in Solids"

ABSTRACT: It is shown using the formalism of Dicke that a crystal composed of identical two-level isomeric nuclei can acquire, through recoilless emission processes, a superradiant state. Selection rules for coherent spontaneous emission of gamma radiation are given. It is shown that, although radiation rates in arbitrary directions are normal, anomalous radiation rates can occur in directions satisfying the Bragg condition.

- * Zaretskii, D. F. and V. V. Lomonosov, ZhETF 48, 368-374; Sov. Phys.-JETP 21, 243 (1965).

ABSTRACT: Conditions for the appearance of a nuclear exciton in a crystal consisting of excited and unexcited nuclei of a given type are examined. The probability for spontaneous emission by a single excited nucleus or by an arbitrary number of excited nuclei in the crystal are derived. It is shown that the formation of a nuclear exciton is connected with an increase of the width of the emitting level and with the concentration of the radiation into a narrow solid angle.

1966

- * Baldwin, G. C., J. P. Neissel and L. Tonks, US Patent 3,324,099, Feb. 8, 1966.
"Method of Preparing a Gamma Radiation Material"

SUMMARY: Describes a method based on the Szilard-Chalmers reaction by which certain nuclear isomers can be prepared in a state of population inversion by neutron bombardment and used for generating coherent gamma radiation in analogy to a maser oscillator.

- Mead, C. A., Phys. Rev. 143, 990-1005.
"Observable Consequences of Fundamental-Length Hypotheses"

ABSTRACT: The postulate of the existence of a fundamental length (FL) may be expressed in terms of a minimum uncertainty in position measurements, or, equivalently, as a minimum uncertainty in measurements of the gravitational field. The postulate is

expressed mathematically by means of "indeterminate operators," whose properties are discussed. With their aid, it is shown that the postulate of a FL has as a consequence a broadening of spectral lines. In the case of a FL of the order of 10^{-13} cm, the predicted broadening is much larger than the widths of nuclear gamma transitions already observed. It is concluded that this FL is in serious contradiction with experiment. In the case of a FL due to gravitational effects of the order of 10^{-33} cm, as previously suggested, the broadening is too small to have been observed in any experiments done to date. A modified Mössbauer experiment is suggested which should be capable of detecting this small broadening, if it is present...

COMMENT: It is suggested that the gravitational red shift be used to scan a recoilless line from ^{103}Rh ; the various sources of broadening of the line are quantitatively examined.

- * Vali, V. and W. Vali, US Patent 3,281,600, Oct. 25, 1966.
"Stimulated Gamma Ray Emission"

SUMMARY: Describes use of a crystal containing radioactive nuclei (e.g. ^{73}Ge) in a state of population inversion as an amplifier for gamma radiation, analogous to a maser amplifier.

1967

Kagan, Yu, and F. N. Chukhovskii, ZhETF Pis'ma 5, 166-170; Sov. Phys.-JETP Lett. 5, 133-136.

"Collective Coulomb Excitation of Nuclei in a Regular Crystal"

SUMMARY: It is shown that, in resonant interaction of γ quanta or particles with nuclei situated in a crystal lattice, a collective state can occur; when it decays, the angular distribution of the γ quanta has a unique character which differs greatly from the usual case. However, the exciting particle must be fast and the isomeric state of a very low energy. The inverse process also is possible.

Lederer, C. M., J. M. Hollander and I. Perlman, Table of Isotopes, 6th Ed., John Wiley & Sons, New York.

SUMMARY: Tabulations of: I. Properties of all radioactive and stable nuclei. II. Information on nuclear states and transitions between them, with diagrams of decay schemes and energy levels. Appendices give fundamental constants and conversion factors, spectroscopic standards, atomic level energies, x-ray energies and yields, and information for estimating photon transition probabilities, lifetimes and conversion coefficients.

Shipman, J. C., Appl. Phys. Lett. 10, 3-4.
 "Traveling-Wave Excitation of High Power Gas Lasers"

ABSTRACT: Experiments are described in which...lasers are excited by a wave of current excitation which effectively travels from one end of the laser to the other, with its velocity matching that of the stimulated emission.

1968

Deslattes, R. D., Appl. Phys. Lett. 12, 133-135.
 "X-Ray Monochromators and Resonators from Single Crystals"

ABSTRACT: Single-crystal specimens shaped so as to permit successive x-ray diffraction by two nonparallel atomic planes are fixed-wavelength monochromators. It is shown that certain plane pairs in Si and Ge pass wavelengths sufficiently close to strong characteristic lines to allow production of intense highly monochromatic beams. For tautozonal planes belonging to the same crystal form, resonators and retroreflectors are possible.

Haeberlen, U. and J. S. Waugh, Phys. Rev. 175, 453-467.
 "Coherent Averaging Effects in Magnetic Resonance"

ABSTRACT: A theory is developed to describe the slow component of the transient decay of transverse spin magnetization and the central component of the slow-passage absorption spectrum, of a system of spins which is subjected to a periodic and cyclic perturbation. The theory is used to analyze and compare various schemes for high-resolution NMR of solids, including the spinning of the sample about an axis oriented at the "magic angle," the rotating-frame magic-angle experiment of Lee and Goldberg, pulsed versions of the latter, and a number of new pulsed-NMR experiments recently developed. Attention is focused on the factors, both theoretical and practical, which are important in obtaining optimal suppression of static dipole-dipole interactions and quadrupole splittings, and retention of chemical and Knight shifts and scalar spin-spin interactions. Several new experiments are proposed.

Hannon, J. P. and G. T. Trammell, Phys. Rev. 169, 315-329.
 "Mössbauer Diffraction. I. Quantum Theory of Gamma Ray and X Ray Optics"

ABSTRACT: The Greens-function techniques of quantum electrodynamics are used to obtain the equations governing the interaction of x rays and γ rays with crystals. In particular, the theory of Mössbauer γ -ray optics for crystals containing resonant nuclei is developed.

Kolpakov, A. V., and R. N. Kuz'min, ZhETF Pis'ma 7, 61-65; Sov. Phys.-JETP Lett. 7, 45-49.

"Correlation Properties of Gamma Beams in the X-Ray Band"

SUMMARY: An experiment is reported which is claimed to demonstrate temporal correlations in photon counts from a beam of Mössbauer radiation that has been divided by a Bragg diffraction beamsplitter.

Labushkin, V. G., and E. P. Nikolaev, ZhETF Pis'ma 8, 560-562; Sov. Phys.-JETP Lett. 8, 341-343.

"Concerning the Correlation of Gamma Quanta in the X-Ray Band"

SUMMARY: It is shown that the experiment of Kolpakov and Kuz'min, which claimed to have observed photon correlations, was incorrectly designed, and that, in fact, no correlations can be observed from an ordinary Mössbauer source.

1969

- * Carlson, D. E. and A. A. Temperley, U. S. Army Nuclear Defense Laboratory report NDL-TR-121, February 1969.
"Possible Resonance Experiments with Long-Lived Nuclear Isomers"

ABSTRACT: The need for measurements of resonance cross sections in long-lived isomers is discussed in relation to the possibility of observing gamma-ray amplification by the stimulated emission of radiation. The resonance-absorption and stimulated-emission cross sections are considered, and the energy-level perturbations that can effectively cause a reduction in the cross sections are discussed in detail. Possibilities for specific resonance experiments are considered and, finally, the most likely candidates for gamma-ray amplification by the stimulated emission of radiation, based on current knowledge, are discussed.

- * Eerkens, J. W., U.S. Patent 3,430,046, Feb. 25, 1969.
"Coherent Gamma Ray Emitter"

ABSTRACT: An emitter for coherent gamma rays comprising an elongated rod of a length-to-diameter ratio in excess of five and preferably between ten and twenty, containing a radioactive isotope of the Mössbauer type. The rod is cooled below the temperature above which the Mössbauer effect therein is substantially suppressed to secure a stimulated emission of gamma rays within the rod and progressive multiplication of gamma rays along the axis of the rod to emit substantially superradiant, directionally coherent gamma rays from an end of the rod. An oscillating magnetic field may be applied axially to the rod at a radio frequency to bring the interaction between an excited nucleus and a conversion electron into substantial resonance to enhance the deexcitation rate between energy states of the

excited nucleus and to introduce at least radio frequency time coherence into the emitted gamma ray beam. Means is disclosed to apply a steady magnetic field transversely to the axis of the rod to orient the nuclei of the radioisotope and cause the gamma rays to be emitted in preferred directions perpendicular to the direction of the field thereby securing a gain in directional coherence of the emission along the axis of the rod. Instead of the oscillating magnetic field the decay rate of the radioisotope may be controlled by the application of monochromatic ultrasonic waves or an electromagnetic beam of a wavelength to bring the internal conversion process of excited nuclei into a resonant condition, the electromagnetic beam being generated by a laser or a microwave generator. Modulation of the various control means for the decay rate of the radioisotope effects modulation of the emitted gamma ray beam.

Hannon, J. P. and G. T. Trammell, Phys. Rev. 186, 306-325.
 "Mössbauer Diffraction. II. Dynamical Theory of Mossbauer Optics"

ABSTRACT: The dynamical theory of Mössbauer optics is developed utilizing the multiple-scattering equations derived in a preceding paper (I). The general optical equations obtained are analogous to the equations of the dynamical theory of x-ray diffraction, but are generalized to account for the very strong polarization mixing which occurs in Mössbauer optics. This polarization mixing leads to a number of interesting features, such as Faraday effects, selective absorption and selective critical reflection. The cases of Bragg reflection, Laue transmission, critical reflection, and off-Bragg transmission are treated in detail.

1970

Hien, P. Z., ZhETF 58, 145-152; Sov. Phys.-JETP 31, 83-86.
 "Spontaneous Emission of γ Quanta by a System Containing Identical Nuclei"

ABSTRACT: Spontaneous γ emission by an excited nucleus, located in a polycrystal or single crystal containing identical (resonant) nuclei, is considered. The problem is solved in the approximation of short wavelengths...Expressions are obtained for the spectrum of γ quanta emitted without recoil and for the time dependence of the rate of emission in different directions. The results obtained can be experimentally verified by the usual method of measuring the lifetime of the excited nuclear state.

Storm, E. and Israel, H. I., Nuclear Data Tables 7, 565-682.
 "Photon Cross Sections.."

ABSTRACT: The report contains tables of photon cross sections in the range 0.001 to 1000 MeV for $Z = 1$ to 100. Supplementary tables of mass attenuation coefficients for air, water, concrete

and sodium iodide; x-ray atomic energy levels; line energies; average energies; relative intensities; and fluorescence yields are also presented.

1971

Aleksandrov, P. A., and Yu. Kagan, ZhETF 59, 1733-1745; Sov. Phys.-JETP 32, 942-948.

"Gamma Rays Emitted by Nuclei in Crystals"

ABSTRACT: We consider the γ decay of excited nuclei in a crystal consisting of the same nuclei but in the ground state. The character of the radiation from a thick crystal is determined by using the reciprocity theorem for absorbing media and the previously obtained solution of the stationary problem of the distribution of γ quanta in an ideal crystal in the case of resonant nuclear interaction with an individual nucleus and the presence of an external source. It is shown that in certain angle intervals the dependence of the decay γ quanta on the thickness is not exponential but follows a power law, this being due to the suppression of the inelastic channels of the nuclear reaction. The radiation from a thick crystal will then be emitted along surfaces of cones with axes along the reciprocal lattice vector and with aperture angle 90° -(the Bragg angle). The character of the angular distribution of the intensity turns out to vary greatly, depending on whether the radiating nucleus is at a site or in an interstice. The possibility of analyzing the position of the radiating nucleus in the unit cell is demonstrated.

Allen, L. and G. I. Peters, J. Phys. A, 4, 377-381.

"Amplified Spontaneous Emission: I. The Threshold Condition"

ABSTRACT: A simple relationship is derived between L_c , the critical length for amplified spontaneous emission...and L_0 , the threshold length of gas that must be excited for laser action to occur in a cavity. The relationship is experimentally verified...

Allen, L. and G. I. Peters, J. Phys. A, 4, 564-573.

"Amplified Spontaneous Emission: III. Intensity and Saturation"

ABSTRACT: A theory is developed to account for the intensity of ASE as a function of the length and diameter of the amplifying medium and of its inversion density...

Casperson, L., and A. Yariv, Phys. Rev. Lett. 26, 293-295.
 "Pulse Propagation in a High-Gain Medium"

ABSTRACT: It is found that ultrashort pulses in a high-gain...laser propagate through the amplifying medium at a velocity less than the vacuum speed of light. The pulse velocity is a function of the gain and agrees with the group velocity.

Kogelnik, H., and C. V. Shank, Appl. Phys. Letts. 18, 152-154.
 "Stimulated Emission in a Periodic Structure"

ABSTRACT: We have investigated laser oscillation in periodic structures in which feedback is provided by backward Bragg scattering. These new laser devices are very compact and stable, as the feedback mechanism is distributed throughout and integrated with the gain medium. Intrinsic to these structures is also a grating-like spectral filtering action. We discuss periodic variations of the refractive index and of the gain and give the expression for threshold and bandwidth. Experimentally we have induced index periodicities in gelatin films..and observed characteristics of laser action.

Peters, G. I., and L. Allen, J. Phys. A, 4, 238-243.
 "Amplified Spontaneous Emission: I. The Threshold Condition"

ABSTRACT: The threshold condition for the onset of amplified spontaneous emission is derived and experimentally verified in the 3.39- μm He-Ne and the 0.614- μm Ne systems. A short discussion is given concerning the confusion between this type of radiation and superradiance.

Shank, C. V., J. E. Bjorkholm and H. Kogelnik, Appl. Phys. Lett. 18, 395-396,
 "Tunable Distributed-Feedback Dye Laser"

ABSTRACT: Efficient broadly tunable dye-laser action with a narrow-line output has been demonstrated with a mirrorless laser system using distributed feedback. The feedback was obtained from a spatial modulation of both gain and index of refraction...

* Pickenbrock, L. J., and E. C. Tibbals, Jr., US Patent 3,557,370, Jan. 10, 1971.
 "Gamma Ray Laser Having a Low Temperature Closed Resonating Cavity"

ABSTRACT: Gamma ray laser device, wherein a coherent beam of gamma radiation is generated through stimulation of gamma transitions in excited atomic nuclei in a biologically shielded and low temperature closed resonating cavity, and wherein said atomic nuclei are externally excited by subjection thereof to radiation produced by electron decomposition (sic).

1972

- * Molchanov, A. G., Usp. Fiz. Nauk. 106, 165-173; Sov. Phys.-Usp. 15, 124-129.

"Lasers in the Vacuum Ultraviolet and in the X-Ray Regions of the Spectrum"

SUMMARY: A review article, containing an extensive bibliography, dealing with the future development of lasers and, in particular, of lasers for wavelengths shorter than presently attained. The possibility of gamma ray lasers is treated only briefly, but the conclusions are optimistic.

- * Khokhlov, R. V., ZhETF Pis'ma 15, 580-583; Sov. Phys.-JETP Letts. 15, 414 (1972).

"Concerning the Feasibility of a γ Laser Based on Radioactive Crystals,"

ABSTRACT: The feasibility of a γ laser based on Mossbauer radiation without transfer of energy to the nuclei in crystals has been discussed in the literature many times. This discussion has revealed serious difficulties that stand in the path of realization of a γ laser, and consequently, in so far as the author knows, no serious attempts at its realization have been made so far. The present article shows that in principle it is possible to produce a γ laser based on radioactive long-lived isomers.

1973

- Afanas'ev, A. M., and Yu. Kagan, ZhETF 64, 1958-1969; Sov. Phys.-JETP 37, 987-1119.

"Suppression of the Inelastic Channels of a Nuclear Reaction in a Crystal Under the Conditions of Hyperfine Splitting"

ABSTRACT: A dynamical theory of the diffraction of γ quanta resonantly interacting with the nuclei in a crystal under conditions of hyperfine splitting is developed. A wide class of cases when complete suppression of the inelastic channels occurs is discovered. The obtained results allow us to find the optimum conditions for the observation of the suppression effect practically from the knowledge only of the hyperfine structure of the ordinary resonant absorption spectrum. As an example, the case of quadrupole splitting is considered in detail.

- * Baldwin, G. C., IIIrd Vavilov Conf. on Non-Linear Optics at Novosibirsk, USSR, June 19-23, 1973. Invited paper, unpublished.
- "On the Possibility of Laser Action Between Isomeric Nuclear States"

ABSTRACT: The history of one of several known efforts to develop a nuclear laser is recounted. At gamma ray energies, the cross section for stimulated emission exceeds that for non-resonant

interaction in many nuclides, so that laser gain is conceivable provided excited states can be assembled in sufficient density. Power density limitations restrict consideration only to isomeric nuclides of long lifetime, produced in nearly pure form by radiochemical procedures. The isomer must be used in the form of a crystal having an appreciable Mössbauer fraction. One then should consider the entire crystalline assemblage of nuclei to be interacting with the radiation field as a single system. Superradiant states as well as avalanches of stimulated emission are then conceivable. However, these considerations appear to be only of academic interest, since the natural line width is so extremely small for nuclides which can be isolated and crystallized that inhomogeneous broadening effects preclude resonance among the nuclei. To overcome such effects (Doppler, gravitational, hyperfine, chemical, concentration, spin-spin, radiation damage) requires physical conditions which appear to be far beyond the capability of present-day technology.

- * Baldwin, G. C., in Laser Interaction and Related Plasma Phenomena, 875-888, Edited by: H. J. Schwarz and H. Hora, Plenum Publishing Corporation, NY.

"Is There a High Frequency Limit to Laser Action?"

ABSTRACT: The existence of an upper limit to the frequency of electromagnetic radiation which can be generated by stimulated emission is considered. Contrary to previous treatments, based on technological limitations of pumping power, it is shown that gain by stimulated emission should be achievable, in principle at least, for photon energies up to several MeV, at which the Compton scattering cross section, augmented by pair production, exceeds the cross section for stimulation.

- * Gol'danskii, V. I., and Yu. Kagan, ZhETF 64, 90-107; Sov. Phys-JETP 37, 49-52.

"The Possibility of Creating a Nuclear γ Laser"

ABSTRACT: The possibility is analyzed in principle of creating a nuclear γ laser with a population inversion produced as the result of pulsed radiative neutron capture. It is found that stimulated radiation can occur only if the Mössbauer effect is used. This imposes severe limitations on the allowable heating of the laser material, which arises unavoidably as the result of cascade γ rays and recoil energy from capture and scattering of neutrons. It is shown that such heating can be avoided if the working isotope is introduced in the form of low-concentration impurities in a light matrix and the laser itself is prepared in the form of thin rods with a diameter to a length ratio of the order 10^{-3} to 10^{-4} . In addition it is necessary that most of the pumping neutrons have an energy of no more than a few tens of eV. Estimates are obtained for the critical concentration of excited nuclei and the corresponding value of critical integrated neutron flux.

- * Gol'danskii, V. I., Yu. Kagan, and V. A. Namiot, ZhETF Pis'ma 18, 61-63; Sov. Phys.-JETP Lett. 18, 34-35.
"Two-Stage Excitation of Nuclei to Obtain Stimulated Gamma-Quantum Emission"

ABSTRACT: We discuss the possibility of increasing the density of excited nuclei if pulsed radiative capture of neutrons with population of the Mössbauer level takes place in one target, and the emitted gamma quanta are then resonantly absorbed in a second target.

- * Goldanskii, V. I., and Yu. Kagan, Vth International Conference on Mossbauer Spectrometry, Bratislava, Sept. 1973.
"On the General Principles and Problems of Realization of Gasers (Gamma-Lasers)"

COMMENT: (This paper is essentially identical to that by the same authors in Sov. Phys-JETP 37 (1973))

- * Khokhlov, R. V., and Y. A. Il'inskii, Proc. IIIrd Vavilov Conf. on Nonlinear Optics at Novosibirsk, June 1973.
"On the Possibility of Creating Gamma-Lasers"

ABSTRACT: Previous studies of the possibility of producing a laser based on long-lived isomers are cited. The causes and magnitudes of the line-broadening effects are analyzed. It is shown that those arising from crystal defects can be reduced, and that the broadening from spin-spin and quadrupole interactions can be eliminated by using techniques already in use in nuclear magnetic resonance research.

- * Kokorin, V. V. and V. F. Los', Fiz. Sverd. Tela 15, Sov. Phys.-Solid State 15, 1186-1188.
Stimulated Emission of γ Rays From Crystals"

ABSTRACT: A possibility of stimulated emission of γ rays with the aid of nuclear transitions is considered theoretically. A kinetic theory of the emission is developed for an impurity (active) center, in whose vicinity local vibrations are generated. Allowance for dynamic effects in the propagation of γ rays in crystals shows that directional mode selection can be achieved using the anomalous transmission of γ rays. Expressions are obtained for the threshold pumping current and for the minimum impurity concentration needed for the stimulated emission. Numerical estimates are obtained and the method of pumping a system of this kind is discussed.

- * Letokhov, V. S., ZhETF 64, 1555-1567; Sov. Phys.-JETP 37, 787-793.
 "The Problem of the Nuclear-Transition γ -laser"

ABSTRACT: The possibility of constructing a γ -laser based on recoilless transitions between the lowest nuclear levels is considered. A distinctive feature of the device is that its operation is based on relatively short-lived isomeric nuclear states with lifetimes of 0.1 to 10 sec. The minimum number of excited nuclei necessary for obtaining appreciable amplification is estimated. The possibility of producing the requisite number of excited nuclei by irradiating a target with a thermal-neutron stream or with resonance γ radiation is considered. Then a low-inertia laser extraction from the target of a relatively small fraction of excited nuclei of a given composition, using the method of two-stage selective photoionization of atoms with excited nuclei by the radiation of two lasers, is considered. It is concluded that in principle a γ -laser of this type can be realized in the 20-60 keV energy range by the considered scheme.

- * Letokhov, V. S., Science 180, 451-458.
 "Use of Lasers to Control Selective Chemical Reactions"

SUMMARY: Conditions and mechanisms for selective photochemical reactions are discussed with application to optical separation both of isotopes and of isomers.

- Morita, M., Prog. of Theo. Phys., 49, 1574-1586, May 1973.
 "Nuclear Excitation by Electron Transition and Its Application to Uranium 235 Separation"

ABSTRACT: A new mechanism for nuclear excitation is studied theoretically by considering the de-excitation of electronic states of atom. When an electron of inner shells is kicked off by the bombarded electron or X ray, an electron of the adjacent shells immediately jumps into the vacancy. The energy corresponding to the difference of the binding energies for these two shells, $E_1 - E_2$, is usually carried away by the emitted characteristic X ray or the Auger electron which is ionized from an outer shell. There is, however, another possibility of this energy release by exciting a nuclear state. That is, the nuclear ground state is excited to the higher energy level by receiving the excess energy of the electronic state by means of electromagnetic interactions between nucleus and electrons. A theory is made for this process, and it is found that the probability of this process is extremely small in most of the cases, but it will be appreciable, if the interaction energy is approximately equal to the energy mismatch $E_N - (E_1 - E_2)$, where E_N is the nuclear excitation energy. An example of ^{235}U is discussed in connection with a possible separation of ^{235}U from uranium isotopes.

Mughabghab, S.F., and Garber, D. I., National Neutron Cross Section Center, Brookhaven National Laboratory, Publication BNL325, 3rd Ed., "Neutron Cross Sections: I. Resonance Parameters"

SUMMARY: A compilation, with explanatory material, of neutron interaction parameters, useful for calculation of neutron capture rates and pumping yields.

Nuclear Data Group, Oak Ridge National Laboratory, D. J. Horen, Director, Academic Press, New York.
"Nuclear Level Schemes"

SUMMARY: A collection of nuclear energy level diagrams taken from the NUCLEAR DATA SHEETS, Vols. 1-9, for reference to nuclear structure and transition information for $A \geq 44$.

* Vinogradov, A. V., and I. I. Sobelman, ZhETF 63, 2113-2130; Sov. Phys. JETP 36, 1115-1119.
"The Problem of Laser Radiation Sources in the Far Ultraviolet and X-ray Regions"

ABSTRACT: As the active medium for a laser in the wavelength region $\lambda \sim 50-150$ A, it is proposed to use a plasma with multiply charged ions expanding into a neutral gas. Such a plasma can be produced by focussing of high-power laser pulses onto solid targets. To obtain gains $k \sim 1 \text{ cm}^{-1}$ in this region, it is necessary to use pumping pulses with an energy of several tens of joules. It is shown that the process of expansion of the hot plasma into a neutral gas can be used to create a powerful source of nonlaser X-rays in the region $\lambda \sim 1-10$ A. The spectrum of this source should contain a small number of narrow lines. The conversion coefficient for pumping energy into a line spectrum of X rays may reach 1%.

Way, K., Editor, Atomic & Nuclear Data Reprints I, Academic Press, New York.
"Internal Conversion Coefficients"

SUMMARY: A tabulation of both partial (by shell) and total internal conversion coefficients, calculated for $30 < Z < 102$.

Waynant, R. W., Proc. IIIrd Vavilov Conf. on Nonlinear Optics at Novosibirsk, June 1973.
"Vacuum Ultraviolet Lasers"

SUMMARY: Discusses the requirements for laser gain in the VUV and X regions and suggests that traveling wave pumping is essential to reduce the power requirement. The application of this principle to a molecular hydrogen VUV laser is described.

1974

Askar'yan, G. A., and V. A. Namiot, ZhETF Pis'ma 20, 332-334; Sov. Phys.-JETP Lett. 20, 148-149.

"Compression and Focusing of a Neutron Gas by Moving the Moderator,"

ABSTRACT: It is shown that when a moderator moves in a neutron gas it is possible to rake the neutrons together and increase their density in the moderator and ahead of the moderator, a fact that can be used to increase the concentration of the reactions induced by neutrons and their energy release, and to enhance self-expansion and self-contraction of a cavity in matter. The possibility of inertial shaking-off and focusing of neutrons by rapid deceleration of matter is demonstrated. The question is raised of the distribution of the neutrons in the medium having a density and velocity distribution.

- * Baldwin, G. C., Rensselaer Polytechnic Institute Contract Report #179 to U.S. Army Ballistic Research Laboratories.
"Problems of the Gamma Ray Laser"

ABSTRACT: An elementary exposition of the problems associated with extension of the laser principle to nuclear transitions: basic lasing mechanisms; properties of nuclear isomers; stimulation cross section and condition for laser gain; nonresonant absorption losses; limiting frequency for lasing; the photon avalanche; causes of line breadth; pumping mechanisms. Stimulated gamma emission requires conditions conducive to the Mossbauer effect in addition to population inversion. Incompatibility of the pumping and lasing processes requires isolation of their environments. Long-lived isomers, readily obtainable radiochemically, emit unacceptably broadened lines; short-lived states require explosive neutron sources with concomitant material damage. Research required to establish feasibility of a graser includes selection of appropriate transitions; developing intense pulsed neutron sources, fast chemical procedures for isomer separation and implantation in crystal hosts; techniques for controlling the inhomogeneous monopole, dipole and quadrupole components of the Mössbauer line breadth; and combination of these diverse elements into a single, compatible system. Grasers may be easier to develop than x-ray lasers of comparable wavelength. Their scientific and technological impact is unquestionable, although, until actual systems can be described, realistic appraisal of their applications is premature.

- * Baldwin, G. C., Laser Focus, 10, March.
"New Look at the Graser"

SUMMARY: Renewed interest, largely in the Soviet Union, in development of gamma ray lasers is described, the problem areas identified, and some newly proposed approaches discussed. In

particular, a traveling-wave fission reaction, driven by laser compression, is suggested.

- * Baldwin, G. C., 1974 Spring Meeting, Optical Society of America.
"Research Problems in the Development of Gamma-ray Lasers"

ABSTRACT: The nearly simultaneous discovery of the Mössbauer effect and the invention of optical lasers stimulated early proposals for generating coherent 10-100-keV γ radiation, using induced transitions in nuclear isomers isolated radiochemically after neutron capture. However, limitation to long lifetimes, inherent in this excitation process, was found incompatible with requirements of resonance, because of inhomogeneous-broadening interactions among nuclear magnetic dipoles and electric quadrupoles, together with gravitational, temperature, and chemical effects. Today, research in laser fusion suggests compact, intense pulsed-neutron sources; research in nuclear isomerism suggests additional reactions for excitation; research in laser photochemistry suggests rapid, quantitative separation of isomers; research in nuclear magnetic resonance has developed methods for reducing spin-spin and quadrupole contributions to line breadth. The feasibility of a graser now depends on finding appropriate nuclear isomers, conceiving ways to combine diverse techniques into compatible systems, and developing methods for controlling line-breadth contributions unrelated to spin. These problems may prove less refractory than those of advancing toward comparable wavelengths via x-ray transitions, because of the wide range of properties of nuclear isomers and the possibility of direct use of nuclear energy for excitation.

- * Byrne, J., G. I. Peters, and L. Allen, Applied Optics, 13, 2499-2504.
"Stimulated Emission from Nuclei."

ABSTRACT: The feasibility of obtaining stimulated emission of both zero and finite mass particles from nuclei is considered, and the limitations imposed on the relevant nuclear parameters determined.

- * Cohen, L., Naval Research Laboratory Memorandum Report #2947
"GRASERS - A Status Report"

ABSTRACT: The concept of the graser (or gamma-ray laser) is discussed and recent Russian and American proposals are surveyed. The difficulties in building a gamma-ray laser are outlined; and specific recommendations are made for delimiting the extent of NRL involvement in graser research in the near future.

- * Dmitriev, V. F., and E. V. Shuryak, Proc. Winter Sch. on Elem. Nuc. & Part. Phys., Leningrad, USSR.
"Possibilities for Creation of a Gamma Laser"

ABSTRACT: Different possibilities for the creation of an active medium for a gamma laser are considered: irradiation by slow neutrons and, in more detail, by quanta of synchrotron radiation. The phenomenon of collective radiation of a system of nuclei is discussed in detail. The kinetics of gamma laser radiation was examined. Experiments possible at the present time are discussed.

- * Dmitriev V. F., and E. V. Shuryak, ZhETF 67, 494-502; Sov. Phys.-JETP, 40, 244-248.
"The Possibilities of Producing a γ Laser,"

ABSTRACT: The possibility is discussed of creating an active medium for a γ laser by pumping by synchrotron radiation. A comparison is made of this scheme with the case of pumping by neutrons. The kinetics of stimulated γ radiation is discussed. The necessary preliminary experiments are discussed briefly.

Douglas, J. H., Science News 105, 8-9.
"Russian Progress on the Nuclear Laser"

SUMMARY: Renewed interest, largely in the Soviet Union, in development of gamma ray lasers is described, the problem areas identified, and some newly proposed approaches discussed. In particular, a traveling-wave fission reaction, driven by laser compression, is described.

Eerkens, J. W., Letter to Laser Focus (May).
"Early Graser Rejection,"

COMMENT: Calls attention to the patent by Eerkens, 1969, claiming it anticipates the Khokhlov-Ilinskii proposals.

- * Fisher, R., Appl. Phys. Letts., 24, 598-599.
Possibility of Distributed-Feedback X-ray Laser"

ABSTRACT: It is suggested that distributed feedback might greatly improve the chances of achieving x-ray laser action in a crystalline material. We have considered the case where the cavity mirror structure is provided by internal Bragg scattering which is distributed throughout the lasing medium. In addition to providing efficient feedback, higher effective gains can be achieved by eliminating the influence of periodic absorbers which occur in selectively x-ray-pumped polyatomic crystals. This is accomplished by establishing a standing wave with its nulls on the periodically spaced absorbers.

- * Gol'danskii, V. I. and Yu. M. Kagan, Usp. Fiz. Nauk. 110, 445-447; Sov. Phys.-Usp. 16, 563-565.
"Feasibility of the Nuclear-Transition γ Laser (Graser)"

SUMMARY: Concludes that the necessary conditions for obtaining stimulated emission from isomers include the Mössbauer effect. The causes and magnitudes of line broadening effects are discussed. Radiative capture of neutrons in an isotope contained in a Be matrix, in the form of a slender needle, is suggested for pumping. Alternatively, transmuted atoms from a large irradiation volume might be collected by recoil. The neutrons must be generated by a nuclear explosion or fusion plasma.

Goldanskii, V. I., S. V. Karayagin, and V. A. Namiot, ZhETF Pisma 19, 625-627; Sov. Phys.-JETP Lett. 19, 324-325 (see also *ibid* 20, 270)
"Compensation of the Inhomogeneous Chemical Shifts of the Mössbauer Line"

ABSTRACT: Proportionality between small variations of the total s-electron density and the spin density at the nuclear site through the Fermi contact interaction makes it possible to devise a method for compensating, with appropriate radiofrequency fields, the most serious source of broadening of Mössbauer lines in long-lived isomers - inhomogeneous chemical (monopole) shifts.

- * Goldanskii, V. I., S. V. Karyagin and V. A. Namiot, Jour. de Physique 35, C6-193-196.
"On the Compensation of a Nonuniform Chemical (Monopole) Shift of the Mössbauer Line"

ABSTRACT: The proportionality between the small variations of total S-electron density and spin density at the site of the nucleus permits a method of compensating by a properly chosen radiofrequency field the most essential source of Mössbauer line broadening: the non-uniform chemical (monopole) shift. The proposed method for narrowing the Mössbauer lines can be used for the precise determination of certain HFS parameters and for starting the operation of a γ -laser (graser). It is also important for the extension of Mössbauer spectroscopy of all problems, which need much narrower lines.

Gol'danskii, V. I. and V. S. Letokhov, ZhETF 67, 513-516; Sov. Phys.-JETP 40, 254-255.
"Effect of laser radiation on nuclear decay processes"

ABSTRACT: The possibility is discussed of observing the effect of ionization of radioactive atoms by laser radiation on the rate of internal conversion (for the case of $\text{Tc}^{99\text{m}}$) and K capture (for the case of Be^7).

Hannon, J. P., N. J. Carron and G. T. Trammell, Phys. Rev. 9B, 2791-2809.

"Mössbauer Diffraction. IIIA. Emission of Mössbauer γ Rays from Crystals. A. General Theory"

ABSTRACT: We develop the dynamical theory of the emission of Mössbauer γ rays from crystals. The direct solution of the multiple-scattering equations, valid in the near and far zones, is obtained along with that utilizing the general reciprocity theorem. As in the x-ray case, the emission pattern exhibits the Kossel cone structure, but there are interesting new features. Enhanced intensity, "anomalous-emission" Kossel lines are predicted in the early development of a radioactive source as a consequence of the fact that the electronic scattering absorption of the lattice is predominately E1, while most Mössbauer transitions correspond to the emission of higher-order-multiple waves. In addition, the sensitivity of the Mössbauer scattering to the magnetic field and electric-field-gradient tensor at the nucleus gives rise to unique Kossel cones which exhibit the structure of the internal fields. Finally, Faraday effects are important in determining the polarization state of emitted quanta. Kossel analysis can also be used to determine the phase of the x-ray structure factor of molecular crystals. In this paper we develop the general theory describing the optics of Mössbauer γ emission from crystals.

Hannon, J. P., N. J. Carron and G. T. Trammell, Phys. Rev. 9B, 2791-2809.

"Mössbauer Diffraction. IIIA. Emission of Mössbauer γ Rays from Crystals. B. Dynamical Solutions

ABSTRACT: The dynamical solutions for the emission of Mössbauer γ rays from crystals are examined. It is found that enhanced intensity "anomalous-emission" Kossel lines occur in the early development of an active source as a consequence of the fact that the electronic absorption of the lattice is predominately E1, while most Mössbauer transitions correspond to the emission of higher-order multipole waves. The sensitivity of the Mössbauer scattering to the magnetic field and electric-field-gradient tensor at the nucleus gives rise to "magnetic Kossel cones" which uniquely exhibit the structure of the internal fields when it differs from the chemical structure of the crystal. Faraday effects are also important in describing the polarization state of the emitted γ quanta. The phase of the x-ray structure factor of (molecular) crystals can be determined by Kossel-cone analysis. Applications of the theory to the problems of obtaining enhanced highly collimated Mössbauer γ -ray sources, and the problems of magnetic and chemical structure determinations by Kossel-cone analysis are presented.

- * Il'inskiĭ, Yu. A., and R. V. Khokhlov, Usp. Fiz. Nauk 110, 448-451; Sov. Phys.-Usp. 16, 565-567.
"The Possibility of Observing Stimulated γ Radiation"

SUMMARY: Addresses the question of using long-lived transitions, for which the line breadth must be reduced before stimulated emission can be realized. The temperature, chemical, magnetic dipole and electric quadrupole contributions to the inhomogeneous line breadth are evaluated. It is shown that all of these effects can be reduced sufficiently.

- * Kagan, Yu., ZhETF Pis'ma 20, 27-30; Sov. Phys.-JETP Lett. 20, 11-12.
"Use of Anomalous Passage Effect to Obtain Stimulated Emission of Quanta in a Crystal"

ABSTRACT: The possibility of increasing the coherent active region in the generation of the paired Bragg state of γ quanta in a crystal by nuclei is demonstrated. To this end it is necessary that the Borrmann effect be realized for one of the polarizations, that the suppression effect be simultaneously absent, and that the state with this polarization be an eigenstate of the crystal.

- * Khokhlov, R. V., Invited paper given at 8th Int. Conf. Q. Elect., San Francisco, Calif., June 1974.
"Gamma-Laser Problems"

ABSTRACT: The two basic approaches to development of gamma ray lasers are discussed. For that based on long-lived transitions, the mechanisms which broaden the Mössbauer line are identified and suggestions for eliminating them are reviewed.

Letokhov, V. S., Usp. Fiz. Nauk 110, 451-452; Sov. Phys.-Usp. 16, 567-568.

"Use of Lasers in Nuclear Spectroscopy"

SUMMARY: This paper considers the possible use of lasers for 1) production of narrow frequency-tunable resonances in nuclear γ -emission; 2) highly accurate measurements of nuclear recoil energies on emission or absorption; 3) highly accurate measurements of the energy of metastable states of nuclei; 4) rapid separation of excited and unexcited nuclei.

- * Letokhov, V. S., Kvant. Elektr. 4, 125-127; Sov. J. Quant. Electron., 3, 360-361.
"Pumping of Nuclear Levels by X-ray Radiation of a Laser Plasma"

ABSTRACT: Theoretical analysis is made of the possibility of the excitation of low-lying nuclear levels by x-radiation pulses emitted by a high-temperature laser plasma. Two- and three-level

pumping schemes are considered. It is shown that, in principle, it should be possible to obtain strong narrow γ -ray lines from recoilless nuclei and to invert the population of nuclear levels.

Naval Research Lab., Washington, D.C.
"ARPA/NRL X-Ray Laser Program"

ABSTRACT: This is the second semiannual technical report for the ARPA/NRL X-ray Laser Program. The individual activities in the program include: electron collisional pumping using picosecond laser heating of a cold plasma; traveling wave (TW) high energy electron beam pumping; nonlinear optical mixing starting with intense 1600 Å radiation; resonant charge transfer pumping using a laser plasma expanding into a neutral gas background, and theory, analysis, and numerical modeling in support of the above and other approaches.

Spiller, E. and A. Seegmuller, Appl. Phys. Lett. 24, 60-61.
"Propagation of X Rays in Waveguides"

ABSTRACT: Waveguide structures and couplers for x rays are analyzed. Experimental results are given for the propagation of Cu K α radiation in guides made of BN.

- * Vorontsov, V. I., and V. I. Vysotskii, ZhETF 66, 1528-1536; Sov. Phys.-JETP, 39, 748-751.
"Concerning the Kinetics of Stimulated Gamma Radiation in the Transient Regime"

ABSTRACT: The singularities of the kinetics of stimulated γ radiation are considered, for various values of the broadening factor, on the basis of a system of quasiclassical equations in the weak-signal approximation, with allowance for the time dependence of the stimulated-emission cross section. The characteristics of the developing wave are compared in the γ -ray band and in the optical band in the transient regime. The concepts of the optimal time interval and the active-layer length are introduced and their values are calculated for a real case.

- * Vorontsov, V. I., and Vysotskii, V. I., Kvant. Elektr. 8, 63-69; Sov. J. Quant. Elect. 8, 63-69.
"Induced Mössbauer Gamma Radiation"

ABSTRACT: The possibility of using ultrasonic excitation to control the frequency and spatial characteristics of induced gamma-radiation in crystals was investigated. It is shown that under certain conditions, phonon excitation can induce narrow lines of gamma-radiation whose shape and amplitude depend essentially on the nature of the ultrasonic excitation. The induced radiation has strong anisotropic features. Problems in the realization of gamma-lasers are discussed, some of which can be overcome by using the principle of induced Mössbauer lines.

- * Wood L. and G. Chapline, Nature 252, 447-450.
"Towards Gamma-Ray Lasers"

ABSTRACT: We suggest that two types of γ -ray laser are possible: a gently pumped variety utilizing isomer separation and the Mössbauer effect, and a vigorously pumped kind using fast neutron excitation of compressed matter.

- * Wood, L., G. Chapline, S. Slutz, and J. Nuckolls, 1974 Spring Meeting, Optical Society of America.
"X-Ray and γ -Ray Laser Studies at the Lawrence Livermore Lab."

ABSTRACT: The unclassified aspects of theoretical and experimental efforts at LLL aimed at attainment of x-ray (XRL) and γ -ray (γ RL) laser operation will be briefly described, and early results noted. Theoretical constraints on XRL and RL operation will be reviewed, and examples of both classes of systems that operate within these constraints will be presented. It will be noted that, although RLs may apparently be operated by use of both highly metastable and fully allowed nuclear transitions, only effectively fully allowed electronic transitions are available for XRL operation. The technological problems associated with quasi-cw and pulsed γ RL operation, especially the timely creation of the required population-inversion densities, will be noted as these two classes of γ RL are compared and contrasted; possible approaches to solution of these problems with currently available means will be suggested. The use of moderately high-power (~ 2 J, 0.1 ns) laser pulses that may be focused to spot sizes of a few dozen micrometers and swept over a few centimeters at the speed of light is suggested to be the technologically most-accessible pumping means that may lead to attainment of XRL action in the keV photon-energy regime. Relatively sophisticated computer codes for the optimized designs of XRLs will be briefly discussed, which permit detailed simulation of pumping-laser energy input, plasma energy and momentum transport, and time evolution of the populations of the electronic levels of ions in the plasma configurations that results from pumping-laser irradiation of both simple and complex XRL targets. Preliminary results of such XRL design calculations will be discussed. Current approaches to the creation of the required XRL pumping-laser system will also be presented. The rationale of the LLL XRL/ γ RL program will be sketched, and reasons presented for expecting XRL and γ RL operation in the next few years along with a brief discussion of possible pitfalls.

Yaviv, A., Appl. Phys. Lett. 25, 105-107.

"Analytical Considerations of Bragg Coupling Coefficients and Distributed-Feedback X-ray Lasers in Single Crystals."

ABSTRACT: Expressions for the coupling coefficients characterizing Bragg x-ray scattering in single crystals are derived. These are used to obtain the threshold gain of a new type of x-ray distributed-feedback laser.

1975

- * Andreev, A. V. and Yu. A. Il'inskii, ZhETF 68, 811-816; Sov. Phys.-JETP 41, 403-405.
"Amplification in a γ -Laser when the Bragg Condition is Satisfied"

ABSTRACT: Amplification of a γ laser under Bragg diffraction conditions is considered. It is shown that the largest gain can be attained in crystals consisting of excited isotopes with maximum multipolarity and minimum nuclear-transition energy.

- * Andreev, A. V. and Yu. I. Il'inskii, ZhETF Pisma 22, 462-465; Sov. Phys.-JETP Lett. 22, 223-224.
"Possibility of Using Anomalous Passage of Gamma Quanta to Intensify Bounded Beams in a Gamma Laser"

ABSTRACT: We consider the question of amplifying bounded wave beams by using the effect of anomalous passage of γ quanta. It is shown that the beam broadening is described approximately by an equation of parabolic type, and estimates are presented for the spreading of Gaussian beams.

Askar'yan, G. A., V. A. Namiot, and M. S. Rabinovich, Usp. Fiz. Nauk 113, 716-718; Sov. Phys.-Usp., 17, 605-606.

"Use of Ultracompression of Matter by Light Reaction Pressure to Obtain Microcritical Masses of Fissile Elements, Ultrasonic Magnetic Fields, and Particle Acceleration"

ABSTRACT: It is stated that, using laser compression, one can achieve criticality in centigram quantities of fissile material, thereby generating 10^{18} neutrons in 10^{-11} s, and that one can also generate magnetic fields of the order of 5×10^9 Oe.

- * Baklanov, E. V., and V. P. Chebotaev, ZhETF Pisma 21, 286-289; Sov. Phys.-JETP Lett. 21, 131-132.
"Concerning One Possibility of Lasing in the Gamma Band"

ABSTRACT: A gamma-ray laser is proposed, based on the use of stimulated Raman scattering to excite nuclei from a long-lived state, which can be prepared radiochemically, to a slightly higher short-lived state which emits the radiation to be stimulated.

- * Baldwin, G. C., and R. V. Khokhlov, Physics Today, 28, 32-39.
"Prospects for a Gamma-Ray Laser"

ABSTRACT: Development of a "graser" may be possible if ways can be found to achieve Mössbauer transitions and population inversion simultaneously in nuclear isomers.

- * Baldwin, G. C., J. W. Pettit, H. R. Schwenn, Proc. International Conference on Mössbauer Spectroscopy, Cracow, Poland 1975, 2, 413-428.
"A Critical Review of Current Proposals for Mössbauer Grasers"

ABSTRACT: Extension of the laser principle to nuclear transitions is suggested by the existence of the Mössbauer and Borrmann effects, the known invertability of some nuclear isomers, and the rapid progress in development and application of lasers at ever-shortening wavelengths. All serious suggestions for grasers assume neutron pumping and recoilless emission, but it is still uncertain that these can be compatible processes. A favorable combination of nuclear level scheme, isomer excitation cross sections, low photon loss coefficient and conditions favoring strong, narrow Mössbauer lines must be reconciled with an intense neutron source requirement. The use of long-lived transitions permits a chemical concentration procedure but necessitates radiofrequency perturbation for reducing the inhomogeneous linebreadth. The acceptable range of transition lifetimes is narrowly restricted by the requirement that the lifetime exceed the period of the perturbation cycle, and hence must exceed the longest reported Mössbauer lifetimes by a greater factor than any yet reported for linebreadth reduction in nuclear magnetic resonance. Use of short-lived, directly excited isomers would avoid linebreadth problems provided the excitation fluence requirements can be met without concomitant severe lattice damage. Here again the transition lifetime is restricted to a narrow range by neutron moderation time requirements on the one hand and inhomogeneous broadening on the other; this is particularly true of indirectly-pumped burst-excited grasers, which involve an additional problem of preparing an unpopulated sublevel of the ground state and cannot use transitions between excited states. Use of the Borrmann effect presents especially stringent demands on lattice perfection. Some numerical example of graser systems illustrative of these problems will be discussed. The most serious shortcoming is the lack of adequate information for evaluating isomer candidates for grasers. Some specific research problems will be suggested.

- * Bowman, C. D., Proposal, private communication.
"Proposal for a Nuclear X-Ray Laser Driven by a Nuclear Explosion"

SUMMARY: It is proposed to incorporate stable ^{82}Kr into a Be host and subject it to neutrons to form ^{83}Kr by resonance neutron capture. The flux of 40-eV resonance neutrons is to be created by moderation of neutrons from an underground nuclear

explosion in a moving moderator, so as to Doppler-up-shift the thermalized spectrum. Design considerations for a graser using this principle are presented.

- * Bushuev, V. A., and R. N. Kuz'min, Usp. Fiz. Nauk. 114, 677-686; Phys.-Usp., 17, 942-947.
"X-ray Lasers"

SUMMARY: A review of current literature relating to the development of lasers for operation in the 100-0.01 Å region of the electromagnetic spectrum. It is concluded that the construction of such lasers can be expected in the near future. A complete bibliography is included.

Elachi, C., G. Evans and F. Grunthaner, Appl. Optics 14, 14-15.
"Proposed Distributed Feedback Crystal Cavities for X-Ray Lasers"

COMMENT: Note proposes the use of zeolite crystals to guide and provide distributed feedback action of self-sustained oscillation at x-ray wavelengths.

- * Gol'danskii, V. I., and V. A. Namiot, Proc. Int. Conf. Mossbauer Spectr., Cracow, Poland, 1975, 2, 479-433, etc.
"Note on the Non-Mossbauer Gamma Ray Laser"

ABSTRACT: The Wood-Chapline variant (A "vigorously pumped" non-Mossbauer gamma-laser pumped by fast neutrons from a laser-ignited thermonuclear reaction) is analyzed. If the parasitic processes (absorption, Compton scattering, inverse bremsstrahlung) and lifetime-transition energy relationships for nuclear levels are considered, this variant is unrealizable.

- * Hannon, J. P. and G. T. Trammell, Bull. Amer. Phys. Soc., 20, 637; Optics Communications, 25, 330-334.
"Anomalous Emission Effect γ -ray Lasers"
"Anomalous Emission Effect and the Possibility of γ -Ray Lasers"

ABSTRACT: The use of the anomalous emission effect in constructing gamma-ray lasers is discussed.

- * Hopf, F. A., P. Meystre, M. O. Scully, and J. F. Seely, Phys. Rev. Letts. 35, 511-523,
"Coherence Brightening and Laser Lethargy in X-Ray Laser Amplifiers"

ABSTRACT: The lethargic response of the lasing medium produced by the combined effects of finite bandwidth and rapid decay of the population inversion leads to a reduction of the linear gain expected in certain x-ray laser amplifiers. However, the effects of coherence brightening are also important, and in the superradiant regime, the laser output approaches that predicted by the usual calculation.

- * Kagan, Yu. M., Proc. Int. Conf. Mössbauer Spectr., Cracow, Poland, 1975 2, 17-41. (In Russian translation available as LA-UR-75-33.)
"Coherent Phenomena in the Interaction of Mössbauer Radiation with Crystals"

SUMMARY: The effects of Bragg diffraction on the gain coefficient for stimulated emission, in a regular crystal of isomeric nuclei are discussed. In addition to the Borrmann effect due to two-wave interference, higher-order interference is considered, for which the nonresonant absorption is reduced by factors much larger than in the two-wave Borrmann case. The requirements for graser amplification are shown to allow only the alternatives of a) reducing nonresonant absorption through standing wave interference, b) reducing inhomogeneous broadening caused by isomer shifts, or c) forming the graser by rapid separation and assembly of a short-lived isomer immediately after its formation. The first two alternatives are discussed in depth. It is shown that the most favorable conditions for stimulated emission from nuclei at regular lattice sites are that the transition be a high multipole, that the pair or multi-wave state of the radiation field have s-polarization and be an eigenstate of the crystal wave field, and that there be no suppression of inelastic channels of the nuclear reaction. A variety of special cases is treated, including that of interstitial active nuclei. Several mechanisms for compensating the inhomogeneous isomer shift are suggested, involving radiofrequency perturbation to control hyperfine splitting or optical radiation to repopulate the S-electron shells.

- * Kamenov, P. and T. Bonchev, Comptes Rendus of Bulgarian Acad. Sci., 28, 1175-1177.
"On the Possibility of Realizing a Gamma Laser with Long-Living Isomer Nuclei"

ABSTRACT: In this work we analyze the possibility of creating a gamma laser by means of isomer nuclei with a long lifetime, whose gamma transition leads to a short-lifetime level. In contrast to other authors, we show here that inverse populations sufficient to start a stimulating intensification can be obtained. At that, the natural width of the gamma transition proves commensurable with the width of the actually emitted gamma-line. This should make it possible to attain critical concentrations sufficient to start a stimulating intensification.

- * Okamoto, K. private communication.
"Possibility of a γ Ray Laser Using Nuclear Excitation by Electron Transition"

COMMENT: Refers to Morita (1973) suggesting nuclear excitation by orbital electron transition might be a superior basis for graser excitation.

- * Svoren, R., Nauka i Zhyzn ("Science and Life") 41, 21-22.
"Planning for a Breakthrough" (Translated by George Krycuk)

SUMMARY: An article, similar to Scientific American articles, devoted to the Russian research on the gamma ray laser. It contains interviews with Khokhlov, Il'inskii, Gol'danskii, Kagan, Letokhov and Namiot, and a color illustration of artist's conceptions for peaceful applications.

- * Solem, J. C., Proposal draft.
"Proposal for Research on Nuclear-Explosive-Driven Mössbauer Effect Gamma-Ray Laser"

ABSTRACT: We propose that LASL undertake a program of research to culminate in a Nevada test of gamma-ray laser (GRASER) initiated by intense neutron flux from a nuclear explosive. Preliminary calculations indicate that such a device is not only plausible but quite reasonable within our present understanding of Mössbauer technology. The success of such a device would be an important achievement for LASL

- * Trammell, G. T. and J. P. Hannon, Bull. Amer. Phys. Soc. 20, 637; Optics Communications, 15, 325-329.
"Threshold Conditions for Pulsed Gamma Ray Lasers"

ABSTRACT: We examine the threshold conditions for both lasing and superradiance in a pulsed γ -ray laser. We find that both threshold conditions are much more restrictive than the Schawlow-Townes condition for lasing in a steady-state laser.

- Zel'dovich, Ya. B. and I. I. Sobel'man, ZhETF Pis'ma 21, 368-370; Sov. Phys.-JETP Lett. 21, 168-169.
"Optical Excitation of Isotopes that are Selective in Nuclear Spin,"

ABSTRACT: We consider the possibility of atomic excitation that is selective in nuclear spin; this possibility is connected with lifting the hindrance to radiative transitions as a result of hyperfine interaction.

1976

- * Andreev, A. V., and Yu. A. Il'inskii, ZhETF 70, 1713-1719; Sov. Phys. JETP 43, 893-896.
"Possible Use of the Borrmann Effect in the Gamma Laser"

ABSTRACT: The efficiency of using Bragg diffraction to amplify finite beams in finite crystals is discussed. The condition under which the plane-wave approximation begins to lose its validity are determined. It is shown that the appearance of modes propagating with weak attenuation is possible in finite crystals. Numerical estimates are given.

- * Baklanov, E. V., and V. P. Chebotaev, Kvant. Elektr. 3, 634-636; Sov. J. Quant. Elect. 6, 345-347.
"Feasibility of Developing a Gamma Laser"

ABSTRACT: A method is suggested for overcoming the obstacles in previous proposals for creation of a gamma-laser. The fundamentally new technique is based on using stimulated resonance Raman scattering in a gas, employing initial-state isomers with a lifetime of 1 to 10^5 s and amplification on nuclear transitions of 10^{-7} to 10^{-15} s. It is shown that the proposed three-level scheme of nuclear transitions could be realized on ^{125}Te .

- * Baldwin, G. C., Los Alamos Scientific Laboratory report LA-UR-75-2349.
"Comprehensive Review of Current Graser Concepts"

ABSTRACT: Interrelated factors associated with gamma-ray laser development (transition lifetime; line breadth; kinetics of excitation, lasing, and neutron moderation; isomer properties and enrichment; photon losses; lattice interactions; and radiation damage) will be quantitatively reviewed.

Note: A summary of this paper was submitted but not accepted for presentation at the 9th International Conference on Quantum Electronics, Amsterdam, Netherlands.

- * Bowman, Charles D. preprint (1976).
"A Nuclear Gamma-Ray Laser Based on Existing Technology"

ABSTRACT: A gamma-ray laser is proposed operating at an energy of 9.3 keV (1.3×10^{-8} cm) in a single-pulse mode with a pulse length of 10^{-7} sec and yields in the range of $10^8 - 10^{11}$ photons per pulse. The laser, pumped probably by photoneutron reactions, apparently can be driven by facilities now in existence.

- * Chapline, G. and L. Wood, Kvant. Elektr. 10, 349-834; Sov. J. Quant. Elect. 6, 452-454.
"X-Ray and Gamma Lasers"

ABSTRACT: The outlook for achieving coherent electromagnetic emission on wavelengths shorter than 1 nm is discussed. It is shown that an x-ray laser could be made by using a pumping arrangement with several laser amplifiers to circumvent problems of nonlinear optical pulse compression and scanning. Analysis shows that for the present it will be possible to make a gamma laser only when we have learned to improve the Doppler width of the emission line. It is suggested that the problems inherent in the Mössbauer crystal method could be avoided by excitation of long-lived isomer states with subsequent condensation of the excited nuclei of the isomers into a crystal. A table is given showing some of the nuclear isomers suitable for this purpose.

- * Gol'danskii, V. I. and V. A. Namiot, Kvant. Elektr. 3, 835-837; Sov. J. Quant. Elect. 455-6.

"Note on a Non-Mössbauer Gamma Laser"

ABSTRACT: An analysis is made of the approach suggested by Wood and Chapline, Nature (London) 252, 447 (1974), for the development of a non-Mössbauer gamma laser pumped by fast neutrons from a laser-induced thermonuclear reaction. It is shown that if allowance is made for the accidental absorption of gamma photons (Compton scattering, inverse bremsstrahlung), processes which were not considered by Wood and Chapline, the gamma laser proposed by them is found to be unrealistic.

Goldanskii, V. I. and V. A. Namiot, Phys. Lett. 63B, 393-394.
"On the Excitation of Isomeric Nuclear Levels by Laser Radiation Through Inverse Internal Electron Conversion"

ABSTRACT: The possibility of observation of inverse internal electron conversion (IIEC) is analyzed. The case treated is the excitation of the isomer $^{235}\text{U}^m$ (73 eV, 26 min) by capture of electrons from a laser-produced uranium plasma with temperature T 50-100 eV.

Il'inskii, Y. A., and R. V. Khokhlov, Izv. vuz. Radiofiz. 19, 792-800; Radiophys. and Quant. Elect. 19, 561-567.

"Possibility of Creating a Gamma-Laser"

SUMMARY: A review that describes the basic difficulties in graser development and possible approaches to either short-lived isomer application or use of long-lived transitions.

- * Jha, S. and J. Blue, Proc. One Hundred Thirty Third Meeting of the Princeton Univ. Conference on Partially Ionized Plasmas including the Third Symposium on Uranium Plasmas, 275-279.

"Considerations to Achieve Directionality for Gamma Ray Lasers"

ABSTRACT: This study concerns a method of alignment of nuclei for a gamma ray laser and a means of achieving preferential emission of radiation along the crystal axis. These considerations are important because it probably is not possible to achieve reflection of gamma radiation in order to have photons make multiple passes through an active region. Atomic alignment has been achieved by materials researchers who have made composite structures composed of needle-like single crystals all with the same orientation and all pointing in the same direction contained in a matrix of cobalt or nickel. The proposed method of preferential emission of radiation along the aligned needles is to have a symmetric field gradient at the nucleus and a sequence of excited levels of spin and parity 2^+ and 0^+ . The

proposed scheme will reduce the density of excited states required for lasing and reduce the linewidth due to inhomogeneous broadening. Mössbauer absorption experiments intended to test these ideas are outlined.

- * Pettit, J. W., and G. C. Baldwin, Los Alamos Scientific Laboratory Report LA-6517-MS
"GRASER—A Kinetics Code for Study of Neutron-Pumped Gamma-Ray Laser Systems"

ABSTRACT: Description, listing, sample plots and operating instructions are given of a computer code for the CDC-6600 which calculates the time and space dependences of the vector potential of a plane wave of recoilless gamma radiation initiated by spontaneous emission and amplified by stimulated emission in a medium of specified properties. The code is based upon a continuous-function approximation of the neutron flux arising from a fast source burst of user-specified intensity in an infinite hydrogenous moderator. A variety of properties of the nuclear transition and of the medium are to be specified by the user, including single-resonance and $1/v$ -capture parameters of the parent isotope; statistical weight factors, isomer inversion ratio and lifetimes of the graser levels; and degree of line broadening, Debye-Waller factor and nonresonant absorption coefficient of the medium.

- * Trammell, G. T., Letter exchange with G. G. Chapline and L. L. Wood, Physics Today, 57-58, July.
"More on X-Ray Lasers"

SUMMARY: An unresolved disagreement on the question of holography of molecules. Trammell asserts that it is impossible, because the molecule would be destroyed by the photoelectric effect; Chapline and Wood disagree.

- * Waynant, R. W., and R. C. Elton, Proc. IEEE. 64, 1059-1092.
"Review of Short Wavelength Laser Research"

ABSTRACT: A review of the status of research towards achieving lasing action in the vacuum ultraviolet and soft x-ray spectral regions is presented. An analysis of the general problems likely to be encountered is accompanied by numerical results for those approaches currently considered promising. Progress on each approach is detailed and various possible methods of verifying the presence of gain with their relative merits are discussed. Research areas requiring application of short wavelength lasers also are given.

1977

- * Andreev, A. V., ZhETF 72, 1397-1406; Sov. Phys.-JETP 45 734-739.
"Superradiance Kinetics of a γ -Ray Laser"

ABSTRACT: An analysis is made of the kinetics of a single-pass mirror-free γ -ray laser. The conditions governing the operation of this laser are obtained. The possibility of Dicke superradiance in the γ -ray range is estimated. The analysis is carried out for single-mode emission from a system of two-level nuclei.

- * Andreev, A. V., Yu. A. Ill'insky, and R. V. Khokhlov, ZhETF 73, 1296-1300; Sov. Phys.-JETP 46, 682-686.
"On the Role of Collective and Stimulated Processes in the Generation of Mössbauer γ Radiation"

ABSTRACT: It is shown that collective spontaneous emission processes play the main role in generation of coherent Mössbauer radiation. Thus observation of stimulated Mössbauer γ radiation involved in the decay of highly excited polyatomic systems is virtually impossible.

- * Baldwin, G. C., Laser Interaction and Related Plasma Phenomena, Helmut J. Schwarz and Heinrich Hora, Eds. (Plenum Press, New York and London, 1977) pp. 249-257.
"On the Feasibility of Grasers"

ABSTRACT: The cross section at resonance for induced gamma ray transitions in nuclear isomers would be adequate for gain if population inversion could be reconciled with recoilless (Mössbauer) emission; the overriding consideration is inhomogeneous broadening from hyperfine interactions and isomer shifts. Feasibility of a graser in which the crystal is pumped by intense neutron burst depends upon the relative rates of isomer formation and development of lattice damage during the time required for neutron moderation and wave incubation; a major uncertainty is the isomer ration. It appears feasible to isolate inverted populations of isomer in quantity adequate for preparing a graser by assembly after irradiation; the limiting factor will be the extent to which the recoilless line breadth can be controlled by as-yet-undemonstrated techniques. Decision on feasibility and identification of transitions suitable for either type of graser await better understanding of these factors.

- * Baldwin, G. C., Laser Interaction and Related Plasma Phenomena, H. J. Schwarz and H. Hora, Eds. (Plenum Press, New York and London, 1977) 4A, 259-266.
"Kinetics of Stimulated Emission in Neutron-Pumped Nuclear Laser Systems"

ABSTRACT: Plane wave solution of kinetic equations for a Mössbauer transition graser, pumped by an instantaneous neutron

burst, shows low group velocity and reduced nonexponential amplification prolonged by superradiance when account is taken of time-dependence ("inertia") in the resonance cross section and of finite neutron moderation time and indicates that directly pumped grasers, assuming that radiation damage and isomer ratios do not preclude their functioning, should employ resonance capture and recoilless transitions between excited states.

- * Baldwin, G. C., and B. R. Suydam, Los Alamos Scientific Laboratory report LA-UR-77-140.

"Kinetics of Neutron-Burst Pumped Mössbauer Gamma-Ray Lasers"

ABSTRACT: The kinetics of a graser system pumped by capture of neutrons moderating from an instantaneous source burst is considered in the weak-signal approximation. The resonant character of interaction of radiation of near-natural line width with resonant nuclei requires that the cross section for the process contain time-dependence which reflects the history of development of the radiation field. Wave development is described by use of electromagnetic wave propagation and dispersion theory, rather than upon photon balance with a time-dependent cross section, although, with retardation neglected, they are shown to lead to equivalent results. Rate equations are written for population densities of the ground and a low isomeric state of a nuclide, being formed by capture of moderating neutrons, using an analytical expression for the neutron flux in a hydrogenous moderator. It is shown how the resulting system of kinetic equations can be solved for the vector potential of a wave initiated by spontaneous emission at the origin, and how the total intensity from an extended filamentary medium can be calculated. Four examples of kinetic behavior of grasers distinguished by details of the neutron capture process are discussed to illustrate the roles of neutron moderation time, energy at which capture occurs, isomer ratio and inhomogeneous line breadth. Since the line breadth, Debye-Waller factor, and nonresonant absorption coefficient may all be time-dependent when consideration is taken of rising temperature and growth of damage during incubation of the wave, use of transitions between excited states formed by resonance capture or inelastic scattering is suggested as a desirable direction for future burst-pumped graser concepts. Suggestions for elaboration and numerical application of the kinetic model are given.

- * Baldwin, G. C., and L. E. McNeil, Los Alamos Scientific Laboratory Report LA-7004-MS.

"Kinetics of Stimulated Mössbauer Emission in Neutron-Pumped Krypton-83"

ABSTRACT: Using an idealized kinetic model for a gamma-ray laser system pumped by a spatially uniform delta-function burst of fast neutrons, a computer study has been made of the growth, decay and attenuation of resonant 9.3-keV recoilless gamma radiation from

^{83}Kr , as a function of neutron burst intensity, gamma-ray linebreadth, temperature, dilution of krypton in a beryllium host, and nonresonant absorption coefficient of the host. The isomer is formed by neutron capture in a 40-eV resonance, and the 144-ns transition lifetime is short in comparison with the time for neutrons to moderate. The kinetic behavior of this system is therefore determined largely by the time dependence of the neutron spectrum and only slightly by the reciprocal linebreadth of the graser transition. Because the lower state is stable, inversion is rapidly lost, so that, for observable gain, an unrealistically high source intensity is needed. Use of a beryllium host, which increases the Debye temperature, is negated by its parasitic absorption. Although this transition is unsuitable for a graser, these findings help to illustrate useful properties of nuclear isomers and solid hosts for which stimulated emission might be observable.

- * Hora, H., G. V. H. Wilson and E. P. George, Australian J. Phys. 31, 55-60.
"Discussion of Laser Conditions and the use of Polarized Nuclei in Grasers"

ABSTRACT: For gamma ray lasers (grasers), a high frequency limitation is derived from the conditions for the laser threshold. At low temperatures the use of polarized nuclei should facilitate the production and observation of graser action using 'Q-switching' by magnetic rotation of the polarization axis.

- * Kane, E. L., Laser and Electro-optik 9, 28-9, 36-8 (in German)
"A Survey of Gamma-Ray Laser Concepts"

ABSTRACT: I. A description of the physics behind directed gamma ray emission is given, together with several technical configurations that may produce its realization. It is concluded that there are a number of difficulties associated with any possible γ -ray lasing method, but they may not be insurmountable. II. Discusses the Mössbauer effect briefly. The concept of a γ -ray laser and possible configurations are then examined.

- * Kopvillem, U.H., V. M. Choodnovsky, Spect. Lett. 10, 349-355.
"Quadrupole Spin Echo Monitor for Gamma-Avalanche Launching"

ABSTRACT: The theory of the gamma-laser launching by means of the quadrupole spin echo technique is constructed. The general steps of the development of the pulsed gamma-laser dynamics are shown.

- * Okamoto, K., Laser Interaction and Related Plasma Phenomena, H. J. Schwarz and H. Hora, Eds. (Plenum Press, New York and London, 1977) 4A, 283-304.

"Possibility of Grasers Using Nuclear Excitation by Electron Transition"

ABSTRACT: It was recently shown that some transitions of atomic electrons can excite the nuclear state, provided that certain conditions are satisfied. This mechanism, called NEET (abbreviation of "nuclear excitation by electron transition"), may possibly be used for a graser. Although the NEET probability is much smaller than the atomic excitation that gives rise to NEET, the life-time of the nuclear state is much longer than the corresponding atomic state, and hence is convenient for pumping. Numerical examples show, however, that the necessary pumping power is much higher than the presently available one, but it can be shown that as far as the excitation rate of the nuclear state is concerned, NEET is superior to other methods, such as direct atomic or nuclear excitation. Future progress of this field may solve the problem of the pumping power, in which case NEET may be used for a graser.

- * Rivlin, L. A., Kvant. Elektr. 5, 2497-2501;
"On Stimulation of Two-Quantum Annihilation of Relativistic Electrons and Positrons"

ABSTRACT: Relativistic electrons and positrons moving together on a counterrunning soft quantum flux, due to the Lorentz transformation of the latter's frequency, can stimulate two-quantum annihilation resulting in hard gamma radiation concentrated within a narrow range of energies and spatial angles. Formulas are presented for calculation of basic parameters and numerical estimations are made.

- * Vysotskii, V. I., and V. I. Vorontsov, ZhETF 73, 54-70; Sov. Phys.-JETP 46, 27-35.
"Amplification in a Parametric Nonthreshold X- or γ -Ray Laser"

ABSTRACT: A theory of coherent parametric nonthreshold X- or γ -Ray amplification is developed. It is shown that in a medium with nonlinear susceptibility and inversion at the idler wave frequency in the optical range, exponential X- or gamma ray amplification with a large increment ($\sim 1 \text{ cm}^{-1}$) should be possible. The amplification is characterized by its nonthreshold nature; i.e., it is independent of the dissipative parameters of the medium at the frequency of the amplified x-(γ)-ray signal (absorption coefficient, line width, etc.). A theory is developed of nonlinear parametric three-frequency interaction with a strongly-dispersive nonlinear medium (with dispersion of the linear and nonlinear susceptibilities) in the field of narrow or broad-band pumping. The feasibility of three-frequency, nonthreshold parametric amplification in a resonant three-level

optically pumped inverted medium with electronic or nuclear Mössbauer transitions is demonstrated. It is shown that an amplification factor $\sim 10^2$ should be attainable by employing Mössbauer γ transitions, a nonlinear medium of ~ 10 cm thickness, and an ordinary laboratory Mössbauer γ -ray source for pumping with an activity ~ 1 Ci.

- * Wilson, G.V.H., H. Hora, D.H. Chaplin, H.R. Foster and E.P. George, Laser Interaction and Related Plasma Phenomena, H. J. Schwarz and H. Hora, Eds. (Plenum Press, New York and London) 4A, 267-282.

ABSTRACT: The high frequency limitation of gamma ray lasers (grasers), the laser condition for feasible densities and the use of polarized nuclei in grasers is discussed. It is shown that, with polarized nuclei, directed emission and switched graser control are feasible. Experimental techniques and results for both resonance and nonresonant rotations of the γ -radiation distributions from polarized radioactive nuclei are presented.

- * Wilson, G. V. H., Appl. Phys. Letts. 30, 213-215.
"Nuclear-orientation techniques for achieving directed radiations from grasers"

ABSTRACT: The advantages of exploiting the anisotropic radiations from oriented nuclei in the development of grasers are pointed out. Nuclear orientation may be achieved by either static or dynamic means. Some simple techniques for switching the direction of nuclear polarization and hence of the radiation emission are summarized.

- * Winterberg, F., preprint.
"The Mossbauer Effect in a Magnetized Plasma and its Application to a Gamma Ray Laser Pumped by an Intense Flux of Neutrons from a Nuclear Explosion"

ABSTRACT: A low- β magnetized plasma behaves like a crystal with respect to ion displacements perpendicular to the direction of the magnetic field. This suggests the possibility of recoilless emission in a direction perpendicular to the magnetic field by the Mössbauer effect. In spite of the anticipated very high temperatures in neutron pumped population inversions, such a magnetic Mössbauer effect should still permit stimulated γ -emission in a direction perpendicular to the magnetic field, since the thermal ion motion is restricted parallel to the magnetic field and thus the emission line broadened only by the transverse rather than longitudinal Doppler effect. Line broadening by the longitudinal Doppler effect inhibits stimulated emission in any direction other than perpendicular to the magnetic field. At the projected plasma densities and temperatures, the required magnetic field strength to form a crystallike magnetized plasma has to be of the order of $> 10^8$ G. A magnetic field especially well suited for this purpose is

that of a linear high current discharge, along the axis of the gamma ray laser rod. The laser rod is pumped by the neutron flux from a nuclear or thermonuclear explosion. If the laser rod is placed in the line focus of a plane Prandtl-Meyer compression, to be realized for example by the supersonic flow inside a trough-shaped curved wall or around a prism, the resulting high compression can be used to greatly amplify the axial current required to reach the high magnetic field, if the initial current is supplied by an explosively driven high current generator.

1978

- Andreev, A. V., and Yu. A. Il'inskii, Sov. Phys. JETP, 43, 893-896, May 1978.

"Possible use of the Borrmann Effect in the Gamma Laser"

ABSTRACT: The efficiency of using Bragg diffraction to amplify finite beams in finite crystals is discussed. The conditions under which the plane wave approximation begins to lose its validity are determined. It is shown that the appearance of modes propagating with weak attenuation is possible in finite crystals. Numerical estimates are given.

- Arad, P., S. Eliezer and Y. Paiss, preprint.

"Nuclear Anti-Stokes Transitions Induced by Laser Radiation"

ABSTRACT: A model and experiment of gamma ray transitions induced by laser radiation is proposed. These nuclear transitions may be a first step towards a gamma ray laser.

- Baldwin, G. C., H. M. Clark, D. Hakala and R. R. Reeves, NBS Special Publication #526, Proc. 12th Info. Conf. Photochem., M. J. Kurylo and W. Brown, eds., 49-50.

"Principles of Photochemical Separation of Isomeric Nuclides"

SUMMARY: Isomer-selective spectroscopic features that can be the basis for achieving nuclear population inversion are considered, with particular reference to separation of the ^{197}Hg isomers, for which all information needed is known. It is shown that combination of Szilard-Chalmers separation with a photochemical enrichment, based upon the distinct hyperfine structure of the 254-nm resonance line, using a frequency-doubled tunable dye laser, should permit an efficient separation. The case of ^{80}Br is also considered; although the isomer shifts are not known, this separation should also be feasible.

- Kuz'min, R. N., Znanie ("Knowledge: News of Life, Science and Technology"), Physics Series. No. 1, 63 pp. (Untranslated--in Russian, Foreword by V. I. Gol'danskii.)

"New Ideas for Gamma Lasers"

SUMMARY: A monograph summarizing the state of graser research as of late 1977. The contents include: 1) General features of

lasers; 2) Gamma resonance fluorescence; 3) The Mössbauer Effect; 4) Long-lived isomers; 5) Gamma lasers with Mössbauer nuclei; 6) Resonators; 7) Possible applications of grasers; 8) Conclusions and recommendations for future research, including further theoretical study of models of graser systems, of the problem of narrowing of Mössbauer lines, and of the kinetics of coherent spontaneous emission. There should be intensive experimental investigation of the line narrowing problem and of phenomena with polarized nuclei, thorough study of nuclear level schemes (under 200 keV) with the aid of advanced and new kinds of detectors. Intense pulsed sources capable of delivering more than 10^{18} neutrons cm^{-2} should be developed. Methods for rapid separation and electrical implantation or epitaxial deposition of isomers from the gas phase should be developed. The search for isotopes with favorable properties should continue. Non-Mössbauer grasers are deemed unlikely (unless polarized-nucleus research produces some unforeseen developments) despite the possibility that cosmic gamma ray bursts may indicate that grasers can exist in nature. The problem is shown to be highly interdisciplinary in nature, but its solution is expected.

- * Schwenn, H. R., M. S. Thesis, Rensselaer Polytechnic Institute, Issued as Los Alamos Scientific Laboratory Report LA-7099-T.
 "A Theoretical Assessment of Radiation Damage Effects in a Proposed Gamma-Ray Laser System"

ABSTRACT: This paper is addressed to the question of the feasibility of pumping a gamma-ray laser (graser) with a nuclear explosion; in particular, to the problem of estimating the reduction of the cross section for stimulated emission, caused by radiation damage associated with neutron pumping. The damage associated with neutron pumping of a graser is assessed in terms of the model proposed by Kinchin and Pease. Expressions are derived for the damage concentration, both static and dynamic, for the energy deposited as heat per primary knock-on atom, and for the temperature rise due to a flux of neutrons in a hypothetical graser crystal, assuming certain models for heat flow. The mechanisms by which radiation damage affects the Mössbauer process are studied, with a review of the literature serving as a basis for empirical assessments of radiation damage effects upon the Mössbauer effect. It is found that the flux requirements for pumping to inversion are more stringent than the limitations upon the flux due to radiation damage considerations. It is concluded that a graser system is more sensitive to the nuclear parameters of the graser material than to radiation damage effects, and that radiation damage diminishes the cross section least in a monatomic metal.

1979

Baldwin, G. C., Nucl. Inst. & Methods 159, 309-330.

"Time-Domain Spectroscopy of Recoilless Gamma Rays"

ABSTRACT: Alternatives to the conventional Doppler-scanning method of Mössbauer spectroscopy, which might offer improved resolution in spectroscopy of recoilless gamma rays, are considered. It is shown that the gamma ray frequency spectrum can be determined by observation of the time-distribution of delayed coincidence counts of photons transmitted by a stationary resonant filter. This may be the best alternative to Doppler scanning for long-lived transitions, especially if experiments to reduce the inhomogeneous linebreadth are to be undertaken. Some practical aspects of the design of systems for making this measurement are discussed, and experiments are suggested which would evaluate the method with known Mössbauer isomers.

- * "Baldwin, G. C. J. C. Solem, Los Alamos Scientific Laboratory report LA-UR-79-409 (Submitted to Nucl. Sci. and Eng.)

"Maximum Density and Capture Rate of Neutrons Moderated from a Pulsed Source: Implications for Gamma Ray Lasers"

ABSTRACT: Heating of the moderating medium limits the density of neutrons that can be moderated from an intense pulsed source of fast neutrons to a specified energy. The corresponding maximum rates of resonance capture, in both light and heavy moderators, are insufficient for the direct excitation of a gamma-ray laser by capture of neutrons from fission or fusion sources.

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