MÖSSBAUER EXPERIMENTS WITHOUT CONVENTIONAL SOURCES

S. Ruby

MÖSSBAUER EXPERIMENTS WITHOUT CONVENTIONAL SOURCES (*)

S. L. RUBY

Argonne National Laboratory, Argonne, Illinois 60439, USA

Résumé. — On discute la densité spectrale élevée du rayonnement émis par les anneaux de stockage des synchrotrons de haute énergie et la probabilité de l'exploitation en tant que source pour spectroscopie Mössbauer. On utilisera la dispersion en temps plutôt qu'en énergie — les avantages potentiels sont décrits, mais non les difficultés.

Abstract. — The high spectral density of radiation from high-energy synchrotron storage rings, and the possibility of its use as a source for Mössbauer measurements, is discussed. Dispersion in time, rather than energy, will be employed — the potential advantages are mentioned, but not the difficulties.

It has been known for some time that the number of X-rays (photons/s/unit solid angle) from high-energy electrons in storage rings will be unprecedented. Less well known is that the spectral density (photons/s/eV/Ω) is also very great. Even for recoilless emission and absorption studies (Mössbauer effect) where the useful line widths may be in a range of 10^{-7}-10^{-9} eV, it is found that spectral density from radioactive sources will be exceeded, frequently by several orders of magnitude. One reference for these statements is Dr. Herman Winick of the Stanford Synchrotron Radiation Project from whose unpublished paper, *Description of the* SSRP, much more information can be found. Figure 1 is adapted from this paper, giving the total photons/s/eV incident on a target 40 millimeters wide by 1 mm high some 10 meters tangentially away from the storage ring with a circulating current of 50 mA. Coherent electronic (Bragg) scattering from a good germanium crystal can cut the white, wide-band spectrum down to a few eV in width with only a small loss of intensity in the peak. For nuclear fluorescence work, the problem is not so much the intensity of the desired beam, but the few billion times larger intensity of undesired nearby radiation. Recall that

$$10^{-9} < \Gamma < 10^{-6} \text{ eV}$$

for $10^{-6} > \tau > 10^{-9}$ s, where Γ is the width and τ the mean life of the nuclear level. There do exist possibilities of discarding most of this undesired radiation using coherent nuclear scattering, but this will not be discussed here. See, for example, ref. [1] and [2].

(*) Work performed under the auspices of the U. S. Atomic Energy Commission.

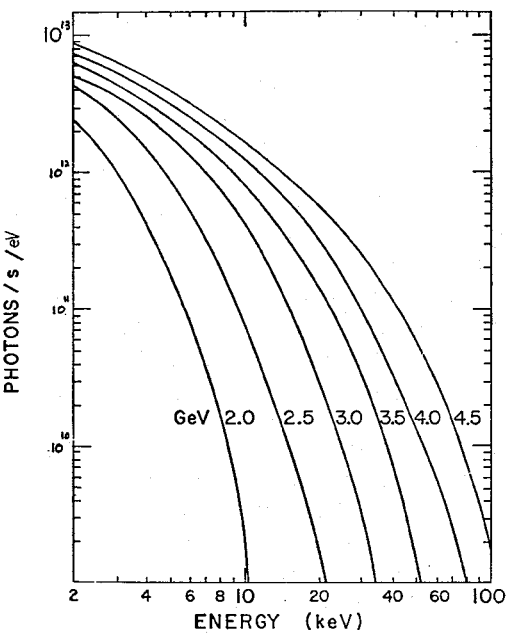

FIG. 1.

The photon beam is nearly 100 % polarized, is only some 10^{-4} radians high in the vertical plane, and will be pulsed at 1.28 MHz with a width of only some 2×10^{-10} s! ! ! This last fact suggests that the separation of the nuclear resonant radiation from the billion times more abundant off-resonant radiation in the 1 eV beam be done mainly in the time domain. Crudely, consider a scattering foil containing nuclei of mean life τ hit by the X-ray beam. The X-ray scattering, Compton scattering, photoelectric effects, etc. are prompt. But if

some of the nuclei are excited by γ-ray absorption, the products (the scattered photon, or the conversion electron, or the X-ray following the internal conversion) of the subsequent nuclear decay will be delayed by about τ. If the detector of these decay products can be gated off during the massive, brief pulse, and quickly restored in about τ seconds after the burst, then this timed resonant detector (TRD) will discriminate very strongly against the non-nuclear resonant X-rays.

Embedded in figure 2, one sees a schematic version of a TRD. Clearly, the detailed design will vary for each

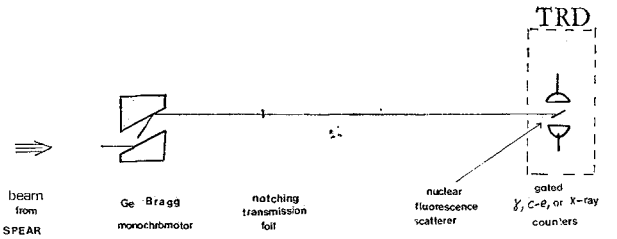

FIG. 2.

nucleus under study. Such factors as the internal conversion coefficient, the ranges of the various decay products, isotopic enrichments, the nuclear lifetime, etc. all strongly affect the detailed design of the TRD. There has been significant earlier work on resonant detectors but without involving time discrimination. Probably the most difficult problem to be faced lies in the large size of the prompt pulse. Some 10^6 photons/pulse, each of say 10^4 eV/photon, will hit the scatterer every microsecond. This will cause a pulse of perhaps 10^6 keV in the detectors ; yet it is desired to measure 10 or 20 keV pulses a few nanoseconds later ! ! An important fact is that this pulse is extremely repetitive, and the electronics can probably be gated to ignore it nearly completely. The major problem will be to restore the detector itself. At present, our hopes center on millimeter slices of Ge or Si for which electron or hole transit times can be less than 10 nanoseconds.

An adequate TRD with the Bragg tuning of the incoming beam will allow measurements of the energy and line width of nuclear resonance fluorescence via absorption. But no hyperfine structure measurements are yet possible. Suppose, however, a simple transmission foil be placed ahead of the detector to *notch* the beam. If a relative velocity is created between the notching foil and the scatterer, then the equivalent of Mössbauer transmission measurements becomes practical. It can be shown that the counting rate as a function of velocity becomes

$$R(v) = \varphi_0 \frac{\Gamma}{E_2 - E_1} * \mathrm{Eff} * [f_n(1 - \varepsilon(t_n, v)) + (1 - f_n)] + B , \quad (1)$$

where $\varphi_0/(E_2 - E_1)$ is the spectral density in the Bragg filtered beam, Γ is the Heisenberg line width of the nuclear level, Eff is the overall efficiency of the detector for resonant radiation, t_n and f_n are the Mössbauer thickness and the recoil free fraction of the notcher, ε is the MB absorption found as usual by convoluting the notching line shape over the scatterer shape, and B is the background. This has been put in a form where the first factor gives the number of photons in the band width, Eff summarizes the overal efficiency of the TRD, and the third factor gives the normalizations for the line shape. The only new term is $(1 - f_n)$ expressing that off-resonant absorption in the notching foil decreases the counting rate ; in ordinary MB work, this disappears since there are no quanta of those energies to be absorbed.

To get eq. (1), the incoming radiation was considered to behave as its power spectra would indicate a uniform density of photons spread over ΔE at E. However, there will be phase relations among the amplitudes which do not appear in the power spectra, and these phase relations possibly could affect the nuclear absorption and/or scattering. We have rederived the synchrotron radiation formulae starting from Lienart-Weichert potentials and find that the relative phases of one frequency with another vary very slowly. However, the Bragg scatterer can introduce new phase relations, but it is likely that these will be too slow to affect eq. (1). However, the description of the transmitted beam as merely « notched » is too simple. Clearly, it must be treated more in the spirit of Lynch, Holland and Hamermesh [3], where the relative phases at various frequencies are maintained. It is this wave packet which is scattered in the TRD, and eq. (1) will become more complicated. The analysis will be similar to that of Theiberger [4] but extended over not the normal γ-ray line shape, but over the synchrotron shape after transmission. Thus, eq. (1) must be improved, and $\varepsilon(t_n, v)$ modified, but the main lines of the experiment will persist.

It is desirable here to point out some of the possibilities when good TRD are available.

(*a*) The beam is born with

$$\Delta\theta \approx mc^2/E \approx 10^{-4} \text{ rad} \approx 20 \text{ s} .$$

Thus for scattering experiments, no beam is wasted in collimation, and high rates will be possible. Consider, for example, the γ-ray mirror experiments of Campbell and Bernstein, or of Wagner.

(*b*) The beam is nearly 100 % polarized. It is not necessary to work with hyperfine splitting and preferential absorbers, etc. as one must from radioactive sources.

(*c*) The timing is built in, and timed experiments do not need detectors of the preceding radiation along with low activity sources.

(*d*) Since the instant for analysis is known, additional pulsed environments become possible. For

example, a laser light could be used to irradiate with a duty cycle of perhaps 10^{-4} to create special environments.

(*e*) Levels can be used which do not have a convenient emission line, e. g., ^{40}K.

A purpose of this talk is to spur members of this community into design of TRDs.

I wish to acknowledge stimulating and useful conversations with Paul Flinn, Herman Winic kand Robert Smither.

References

[1] KAGAN, Y. and AFANASE'EV, A., Chapter in *Mössbauer Spectroscopy and Its Applications*, IAEA, Vienna (1972) « Coherence Effects During Nuclear Resonant Interaction of γ Quanta in Perfect Crystals ».

[2] MIRZABABA'EV, R., SMIRNOV, G., SKLYAREVSKII, V., ARTEMEV, A., IZRAILENKO, A. and BABKOV, A., *Phys. Lett.* **37A** (1971) 441 « Purely Nuclear Diffraction of Resonant Gamma Rays Due to Hyperfine Quadrupole Interaction ».

[3] LYNCH, F. J., HOLLAND, R. E. and HAMERMESH, M., *Phys. Rev.* **120** (1960) 513 « Time Dependence of Resonantly Filtered Gamma Rays from ^{57}Fe ».

[4] THIEBERGER, P., MORAGUES, J. A. and SUNYAR, A. W., *Phys. Rev.* **171** (1968 2 « Time Dependence of Mössbauer Scattered Radiation ».