BNL--34300

DE84 014379

A NORMAL-INCIDENCE MONOCHROMATOR BRANCH LINE ON THE FEL-UNDULATOR FOR EXPERIMENTAL STUDIES IN THE 5-30 eV REGION

P. D. Johnson, N. G. Stoffel
Physics Dept., Brookhaven National Lab., Upton, N.Y. 11973 U.S.A.

R. Klaffky
N.S.L.S., Brookhaven National Lab., Upton, N.Y. 11973 U.S.A.

N. V. Smith
Bell Laboratories, 600 Mountain Avenue, Murray Hill, N.J. 07974 U.S.A.

January 1984

The submitted manuscript has been authored under contract DE-AC02-76CH00016 with the Division of Basic Energy Sciences, U.S. Department of Energy.

A NORMAL-INCIDENCE MONOCHROMATOR BRANCH LINE ON THE FEL-UNDULATOR FOR EXPERIMENTAL STUDIES IN THE 5-30 eV REGION

P. D. Johnson, N. G. Stoffel
Physics Dept., Brookhaven National Lab., Upton, N.Y. 11973 U.S.A.

R. Klaffky
N.S.L.S., Brookhaven National Lab., Upton, N.Y. 11973 U.S.A.

N. V. Smith
Bell Laboratories, 600 Mountain Avenue, Murray Hill, N.J. 07974 U.S.A.

ABSTRACT

The proposed installation of an experimental beam line to exploit the photon flux from the FEL Undulator on the Brookhaven VUV ring is described. It is shown that under the normal operating conditions of the VUV ring the Undulator should produce an intense flux of photons in a highly collimated beam in the energy range from 5-200 eV.

It is intended to construct a beam line based on a McPherson 225 monochromator which will allow an experimental program in the range 5-30 eV. The optical layout of the beamline is discussed with particular emphasis on the requirements of coupling a highly collimated source to such a monochromator.

The experimental program is designed to utilize either the high photon flux with medium resolution or a more modest flux with the potential high resolution to be obtained from the monochromator. Planned experiments include High k-space resolution Angle-resolved photoemission, high resolution gas phase studies and spin resolved photoemission from solid surfaces.

1. Introduction

As our ability to exploit the radiation from storage rings has improved, it has been widely recognized [1] that the use of insertion devices, i.e. undulators and wigglers, can extend the scientific frontiers that are attainable with this research tool. The primary reason for this improvement is that an insertion device produces an extremely high flux of photons into a well collimated beam. Furthermore with careful choice of parameters these devices may be constructed to operate over any part of the spectrum currently available from storage rings or to extend this range to longer or shorter wavelengths.

This paper describes a VUV beamline, now in the process of fabrication, which has been designed to use the radiation from the Free Electron Laser (FEL) Undulator [2] recently installed on the VUV ring at Brookhaven. It is intended that this beamline will provide monochromatic light in the wavelength range from 1500 Å down to 300 Å and that this radiation will be available during the normal operating cycle of the VUV ring.

2. The FEL Undulator

Insertion devices have been described in detail in numerous publications elsewhere [3]. Briefly, temporal coherence of the wavefronts emitted from a series of equally spaced points along the axis of the Undulator produces a spectral output, which is peaked at some fundamental frequency and at harmonics of this frequecy.

The wavelengths of the fundamental and harmonics are given by [3]

$$\lambda_n = \frac{\lambda_o}{2n\gamma^2}(1 + K^2 + \gamma^2\theta^2), \; n = 1,2,3... \quad (1)$$

where λ_0 is the Undulator period, γ the electron energy in rest mass units, θ the observation angle with respect to the Undulator axis, and K the magnetic strength parameter.

This radiation will be emitted into a beam with horizontal divergence given by [4]

$$2\theta^h_{1/2} \approx 2\ K/\gamma \quad (2)$$

where $2\theta^h_{1/2}$ is the full horizontal angle. The vertical divegence is given by

$$2\theta^v_{1/2} \approx 2/\gamma \quad (3)$$

The FEL Undulator which is of the permanent magnet type has been designed to work with the VUV ring operating at an energy of 350 MeV, giving a fundamental wavelength of 3500 Å. However under normal operating conditions, the VUV ring has an electron beam circulating with an energy of typically 750 MeV. At these energies the spectral output of the Undulator has shifted to a different energy range and an example is given in Fig. 1 for magnetic strength parameter K = 2 [5].

From the figure it will be seen that the spectral output is not unlike the synchrotron radiation output from an arc source but with the addition of very small peaks superimposed on this background. The output is greater than 10^{16} photons/sec/amp of stored current (equivalent to approximately 500 mrad of an Arc source) over a wavelength range from 2000 Å to 30 Å. From equation (2) this radiation will be emitted into a beam having an angular spread of approximately 3 mr. Thus we appear to have an excellent source of photons for most experiments.

3. Beamline

There exist many possibilities for exploiting the radiation emitted from an Undulator and the beamline proposed here should not be considered an optimized design. Consideration of equations 2 and 3 shows that the vertical divergence unlike the horizontal divergence is independent of the magnetic strength parameter K. This combined with the polarization dependent reflectivity of the mirrors argues in favor of the use of vertical dispersion rather than horizontal dispersion. However, the aim has been to achieve a reasonable match to an existing monochromator given the rather tight space constraints currently existing in the VUV experimental hall.

A beamline has been designed which uses a McPherson 225 monochromator to provide monochromatized light in the wavelength range from 1500 Å to 300 Å. Figure 2 shows a schematic diagram of this proposed beamline which includes as key components in the entrance arm, a plane mirror to deflect the beam towards the monochromator and an ellipsoidal mirror (demagnification 20:1) to refocus the beam on to the entrance slits of the monochromator. After the McPherson monochromator, which has been adapted for ultrahigh vacuum ($\leq 10^{-10}$t), the exit arm consists of movable exit slits to allow for optimization of the resolution and an ellipsoidal/plane mirror combination (magnification 1:1) to refocus the light into the experimental chamber.

The total radiated power from the Undulator is [3]

$$P(\text{watts}) = 3.8 \times 10^{-6}\ N\gamma^2K^2I/\lambda_0(\text{cm}) \qquad (3)$$

which for a beam stored at an energy of 750 MeV and a magnetic strength parameter K of 2 will be approximately 195 watts/amp of stored current. This potentially damaging power leads naturally to the idea of an "expendable" water cooled plane mirror as the first element in the beamline.

4. Optical Design

As stated earlier the Undulator is a device that produces a high flux of photons into a highly collimated beam. However this beam has emerged from an extended source, in the present case a source 2 m in length. Ray tracing [6] has been employed to explore the degradation in focussing properties of the ellipsoidal mirror used to refocus such a source and the results are shown in Figure 3. From this figure it will be seen that approximately 80% of the emitted beam should be focussed into an area 50 μ in width. Note that these calculations are for a point source which is moved along the 2 m length of the undulator. The horizontal width of the source is ≈ 1 mm and so the width of the image on the entrance slit will after demagnification be ≈50 μ. Thus we expect to be able to image almost all of the 3 mrad beam into rather narrow slits. For the McPherson 225, a half width resolution of 0.15 Å is obtained with 10μ slits and a groove density of 1200 lines/mm on the grating. It is hoped therefore that with the combination of grating and slit width in the present experiment resolutions of the order of 10 mV should be obtainable.

The horizontal angular divergence after the entrance slit is 60 mrad slightly less than that required to fill the standard 96 mm wide McPherson 225 gratings (Bausch and Lomb catalog numbers 35-52-18-410 — 35-52-25-150).

Examination of the spectral output [5] of the Undulator, Fig. 4, reveals that the fundamental and odd harmonics fall on the central axis and the even harmonics tend to have their maximum off axis. This configuration will be maintained throughout the optics of the beamline and thus it is intended to use gratings with high groove density, 2400 lines/mm, to maximize the number of grooves illuminated by any particular harmonic.

This anisotropic distribution may be exploited to advantage by the use of either a central aperture or baffles, which block the outside edges of the beam and thus the second order if one is using the fundamental wavelength. The optimum place for such a device would be before the entrance slits of the monochromator.

5. Summary and Outlook

In summary it is hoped that this Undulator based beamline will provide an intense source of monochromatized light in the wavelength range 1500 Å - 300 Å.

A scientific program is planned that will exploit either the high flux of photons with medium resolution or at the cost of a more modest flux use the high resolution obtainable from the monochromator. This program includes high k-space resolution angle resolved photoemission, spin resolved photoemission, and high resolution photoemission in the gas phase.

It is also intended to explore the output of the Undulator in more detail and gain more insight into the use of such a device for experimental programs.

Acknowledgements

The authors are pleased to acknowledge useful discussions with S. Krinsky, D. E. Aspnes and M. R. Howells. This work is supported by the Division of Materials Sciences, U. S. Department of Energy under contract DE-AC02-76CH00016.

References

1. J. E. Spencer and H. Winick, p. 663-716 in "Synchrotron Radiation Research", ed. by H. Winick and S. Doniach, Plenum Press, N.Y. 1980.

2. A. Luccio, P. Motazavi and L. Yu, Nucl. Inst. & Meth., to be published.

3. S. Krinsky, M. L. Perlman and R. E. Watson, Chapter 2, "Handbook on Synchrotron Radiation," ed. by D. E. Eastman and Y. Farge.

4. S. Krinsky, W. Thomlinson and A. van Steenbergen, BNL Report #31989, 1982.

5. S. Krinsky, private communication.

6. D. E. Aspnes and S. M. Kelso, Nucl. Inst. and Meth., Vol. 195 (1982) p. 175-181.

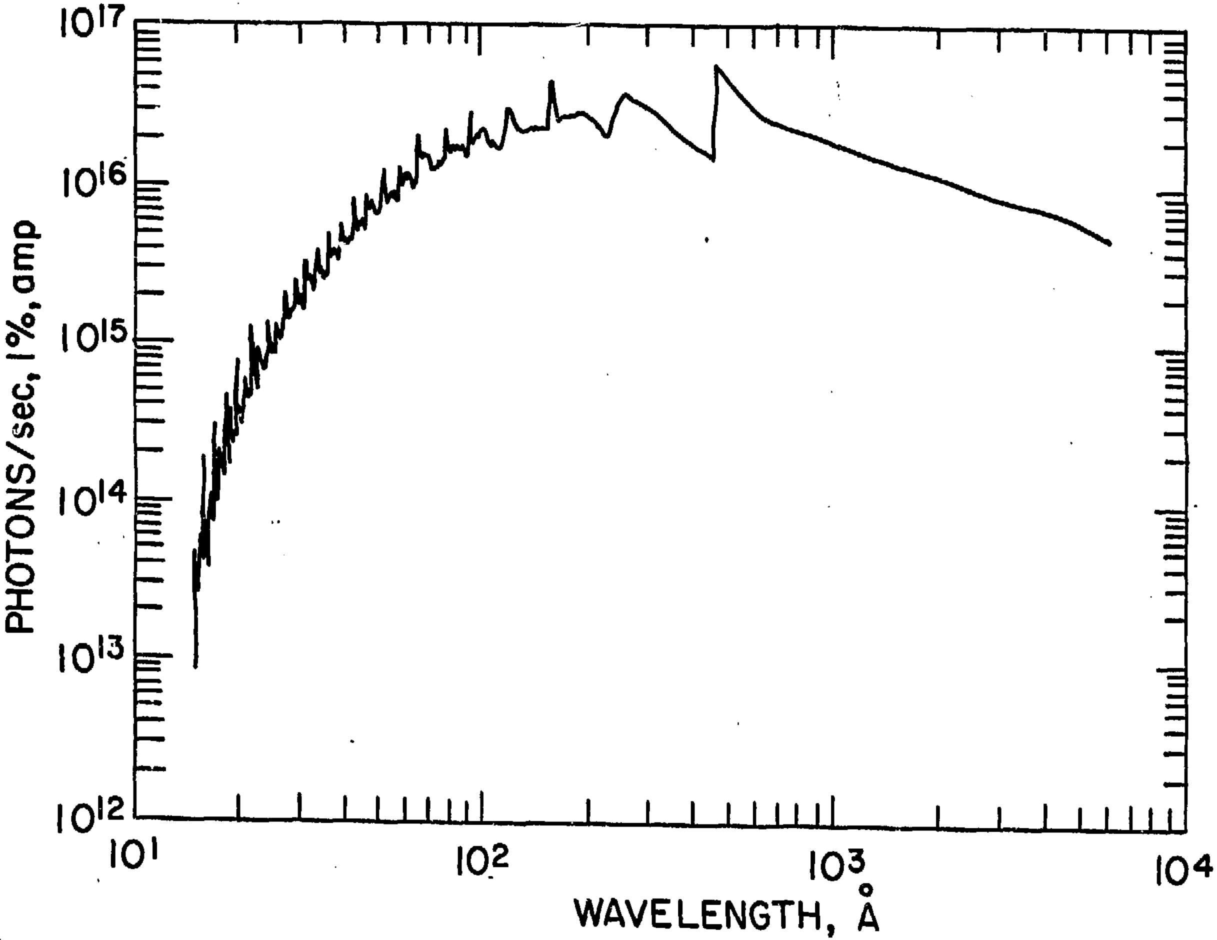
Figure Captions

Fig. 1. The spectral output of the undulator with stored beam energy of 750 MeV and magnetic strength parameter K = 2.

Fig. 2. The proposed beamline on the FEL Undulator. Key components include: A plane mirror, B entrance ellipsoidal mirror, C McPherson 225 monochromator, D ellipsoidal/plane mirror combination and E experimental chamber.

Fig. 3. Ray tracing for the entrance ellipsoidal mirror showing the image obtained on the entrance slits of the monochromator from an extended source 2m in length. Inset in upper left hand corner shows the source divergence characteristics. x - Source point at front of undulator; • - Source point at center of undulator; ∘ Source point at back of undulator.

Fig. 4. Angular distribution of the spectral output from the undulator. $\phi = 0$ corresponds to the plane of the storage ring; $\phi = 90°$ is perpendicular to this plane.



PHOTONS/sec, 1%, amp
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{1}
10^{2}
10^{3}
10^{4}
WAVELENGTH, Å

Fig 1

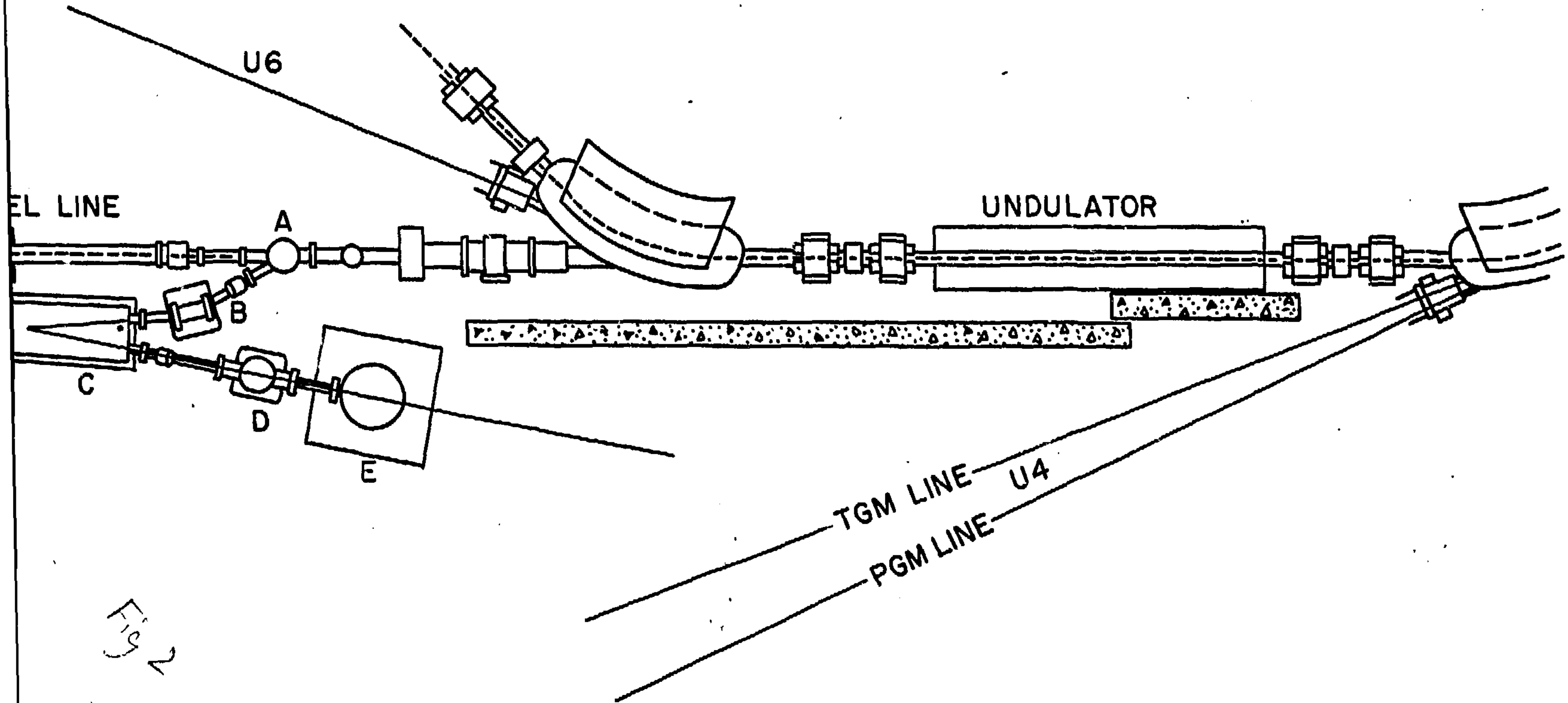


Fig 2

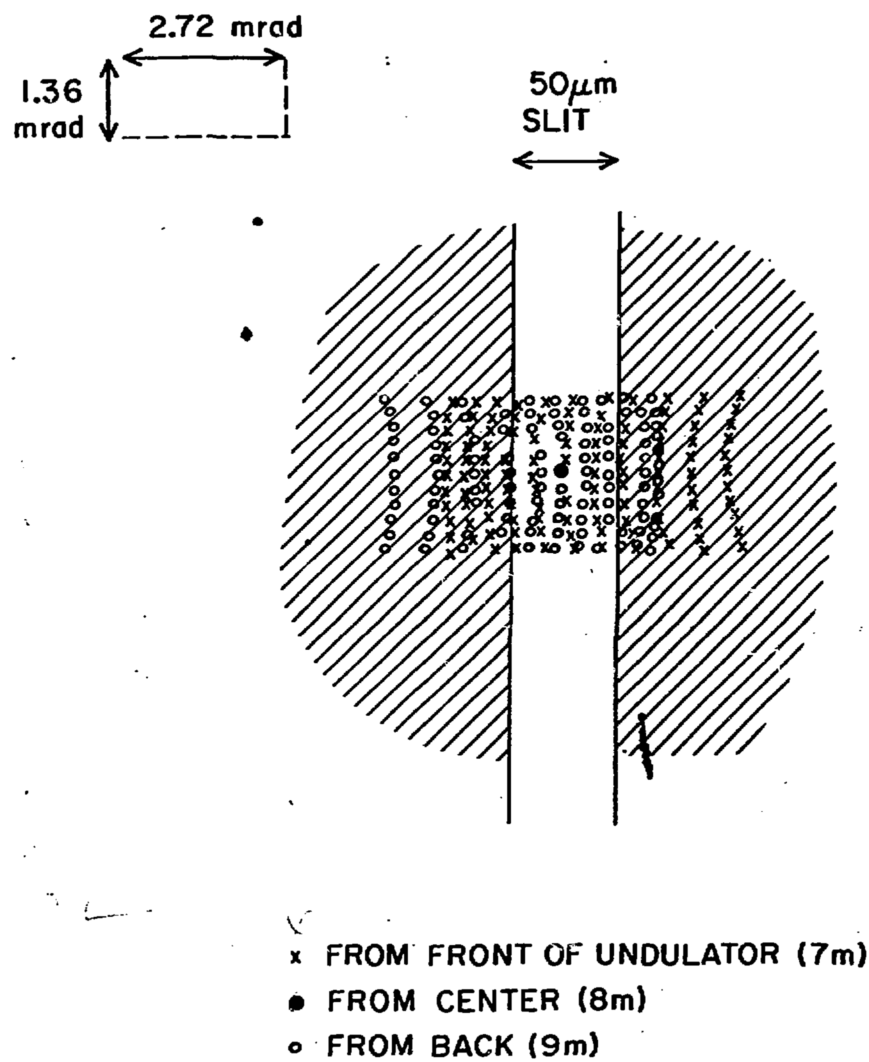

2.72 mrad
1.36 mrad
50μm SLIT
x FROM FRONT OF UNDULATOR (7m)
● FROM CENTER (8m)
o FROM BACK (9m)

Fig 3

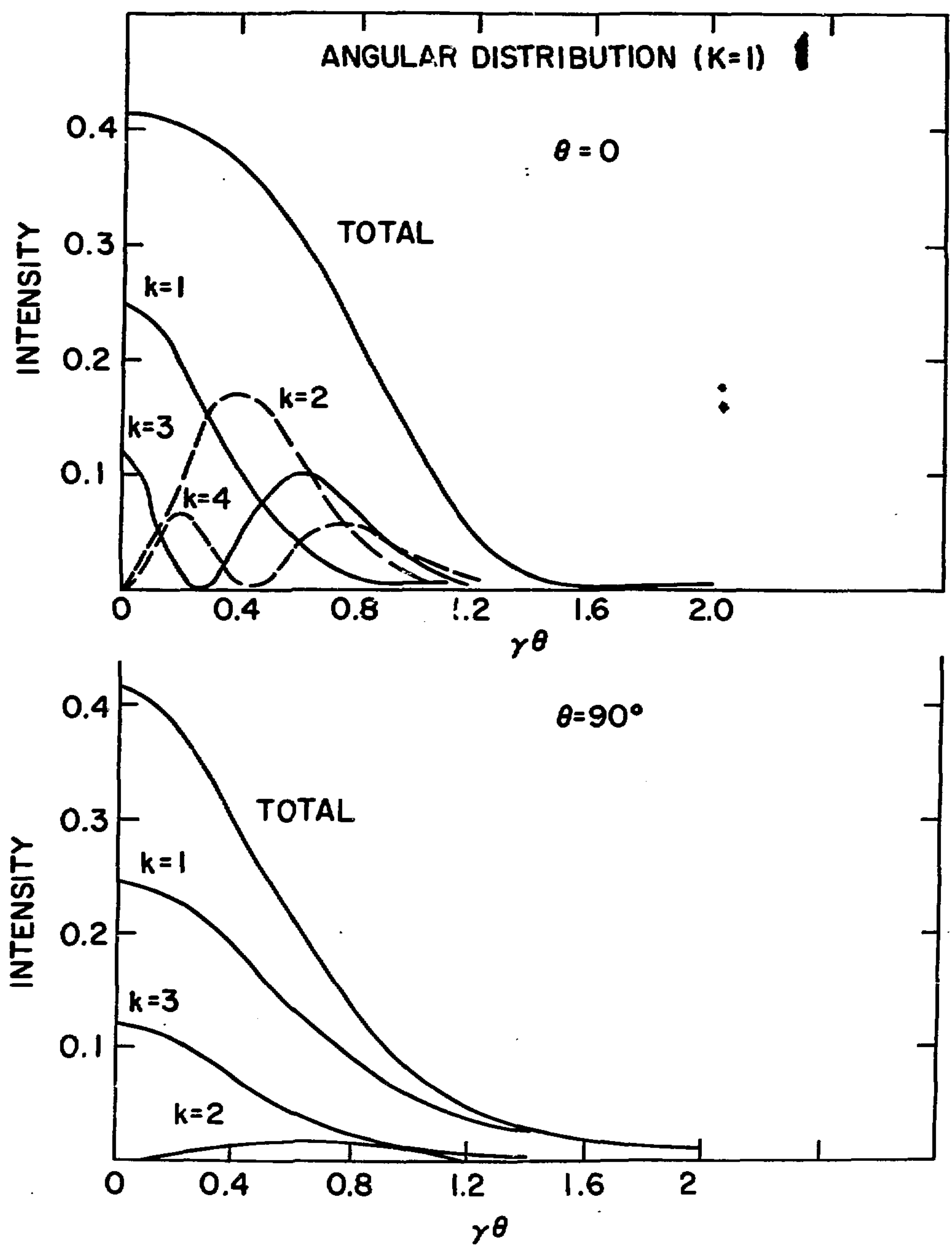

ANGULAR DISTRIBUTION (K=1)
θ = 0
TOTAL
k=1
k=2
k=3
k=4
INTENSITY
0.4
0.3
0.2
0.1
0
0.4
0.8
1.2
1.6
2.0
γθ
θ=90°
TOTAL
k=1
k=3
k=2
INTENSITY
0.4
0.3
0.2
0.1
0
0.4
0.8
1.2
1.6
2
γθ

Fig 4