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Grazing Incidence Spectrometers, Crystal Spectrometers and Scattered Light Problems

by

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Grazing Incidence Spectrometers, Crystal Spectrometers and Scattered Light Problems[≠]

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More than ten monochromator mountings for the wavelength region 1 - 400 Å, which are constructed to operate with synchrotron radiation, are reviewed. The problems encountered when matching the instruments to the synchrotron source are discussed. Special attention is given to knowledge obtained at DESY.

1. Introduction

Electron accelerators and storage rings are definitely unique light sources in the vacuum ultraviolet and x-ray regions but for most of the applications it is only possible to estimate their usefulness if one looks at them in connection with a specific monochromator. The basic properties of synchrotron radiation and the varying properties of existing accelerators have been dealt with in a previous paper (Haensel) while in another paper (Namioka) a review of normal incidence monochromators was given. My topic covers the monochromators for the soft x-ray region and the x-ray region proper. I will refer to some of the facts given in the other papers and in other reviews[1-6].

[≠] Reported at the International Symposium for Synchrotron Radiation Users, 5-7 January 1973. (This is a revised version)

The new aspects which cause some of the differences as compared to classicals sources, arise from the complexity and immovability of the accelerators (a situation comparable to astrophysics and plasma diagnostics). Further, due to geometrical and health physics restrictions, the minimum distance of the monochromators from the source varies between 3 and 40 m depending on the size of the accelerator. This disadvantage is outweighed by the good collimation of the radiation emitted. Since synchrotron light is polarized horizontally vertical reflection and dispersion planes are preferred a situation also very unusual in classical applications.

In the normal inicence regime a single new type of monochromator, especially adapted to the source geometry of a synchrotron was developed during the past few years. The DESY-München instrument[7], due to its simplicity, is an almost ideal instrument for medium resolution (1 Å) spectroscopy in the long wavelength region (400 - 2000 Å) demanding only a single optical component. In the grazing regime with its more difficult problems (e.g. superposition of higher orders and complicated imaging) several new instruments were developed in addition to the classical Rowland mounting. Exploitation of the x-ray part of synchrotron radiation is only very recent. Only a few concepts exist on how to monochromatize synchrotron light there.

2. Synchrotron parameters

2.1 Acceptance window

One of the most important numbers characterizing any monochromator synchrotron combination (storage rings are included in this term) is the number of photons per unit energy interval and per second which are accepted by the entrance aperture of the monochromator. This number is readily calculated from the well known equation for synchrotron radiation. Fig. 1 gives this number for a square aperture 2 cm by 2 cm located at a distance of 40 m from the source for DESY and the electron-positron storage ring DORIS which is under construction on the DESY site. In the soft x-ray region apertures of ∿30 % of that given are realistically achieved. In the x-ray region radiation is confined to the plane of the synchrotron anyhow.

In comparing differant synchrotrons at wavelenths much longer than λ_c (the cut-off wavelength) the most important parameter is the electron current. Care should be taken because it is usual among accelerator constructors to give the current during duty cycle rather than the average current.

2.2 Size of the source

Another decisive factor is the size of the electron beam in the accelerator. For some of the monochromators it constitutes the entrance slit, for others it is imaged into the entrance slit. The smaller the beam the better. At DESY its size under normal conditions is 3 mm (vertically) x 10 mm (horizontally). With high currents and high energies in the accelerator the electron beam blows up considerably. Storage rings can have much smaller widths of beam. It is wise to design the instrument so that the small width falls in the direction of dispersion.

2.3 Distance from the source

According to the principal laws of optics the distance between source and monochromator ought not to be a decisive parameter because changes in the distance can be compensated for by imaging devices. The main goal is to match the acceptance of the monochromator with the emittance of the source.

(Emittance/acceptance is defined as the size of the source at focus times the angular width in both vertical and horizontal directions.) With the practical restriction of optical elements in the grazing incidence region, however, the parameters of the monochromator should be chosen, if possible, in such a way as to avoid additional optical elements. All these components have a fairly small useful acceptance and a low reflectance. Both large and small distances can be an advantage in this respect depending on the design of the instrument.

3. Grazing incidence monochromators

3.1 Optical elements and scattered light problems

3.1.1 General remarks

Many of the optical elements used with synchrotron radiation are just the same as in classical grazing incidence applications and are well summarized in the book by Samson[8]. Nevertheless, a few points of special importance ought to be stressed here. The following details are based primarily on experiences gained by the DESY group. Unfortunately, available technical information as to stray-light, higher orders, best reflectivity coatings etc. is only spurious and very incomplete.

3.1.2 Gratings

At least in the region above 40 Å blazed gratings proved to be superior to lightly ruled gratings[9]. Gratings blazed for long wavelengths at normal incidence mostly turn out to also have the right blaze at grazing incidence according to the following equation:

$$\lambda_B' = \lambda_B \cos (\alpha - \Theta_B) \qquad (1)$$

with $\lambda_B = 2d \sin \Theta_B$, where d = grating constant, Θ_B = blaze angle, λ_B = Littrow blaze wavelength (λ_B is usually listed in catalogues and is the relevant blaze wavelength for any near normal incidence mounting), α = angle of incidence, λ_B' = effective blaze wavelength. Of course the grating is blazed also for λ_B'/n in n-th order. The contribution of higher order radiation at a specific setting of the instrument depends on:

1. the relative intensity of different wavelengths in the spectrum. This can be influenced by filters (Al is the only really good one cutting off wavelengths below 170 Å thereby reducing stray-light simultaneously),
2. the angle of incidence on the grating,
3. specific gratings. Figure 2 gives an example of the performance of two gratings[9]. We have plotted the ratio of n-th to first order light not for a fixed setting of the instrument (a 1 m Rowland) but for specific wavelengths. This quantity, which is characteristic of a grating at a given angle of incidence, is obtained by measuring prominent structures (edges) in absorption in different orders. Figure 2 shows that there is a drastic variation of this quantity with different gratings.

Figure 3 gives a characteristic spectrum obtained with a plane grating in a very simple arrangement[10] (see Fig. 5a). Such spectra are typical for mountings having a fixed angle of incidence on the grating. (Occasionally it is preferable to give the grazing angle of incidence $\phi = 90^\circ - \alpha$.) Extrapolation of the intensity between zero order and the beginning of the spectrum gives a rough estimate of the amount of stray-light present. ($\sim$1 % in Fig. 3). The stray-light contribution varies strongly depending on the materials investigated and the filters applied. Thickness variation (resp. pressure variation with gases) of the absorber is the only way to properly determine the stray-light contribution[11].

3.1.3 Surface coatings

One of the physically disappointing but instrumentally advantageous properties of heavy metal coatings is that they do not add much structure[11] to the spectra. With Au coatings (which are used preferentially) only slight structure appears at the $N_{6,7}$ edges[12] (87.6 eV and 84.0 eV). Unfortunately, measured reflectivities of Au coatings (which are occasionally exposed to air) are not available. Figure 4 gives values measured on Pt by Römer[10]. This material is sometimes used as a surface coating. Quite generally, the reflectivity curves show the behaviour expected for the cut-off angle of total reflectivity but the reader should be reminded that reflectivity will not rise steeply in regions of high absorptivity[8]. This occurs with Pt (and also Au) at photonenergies below 100 eV. Figure 4 shows reflected intensities to be low at the angles needed to suppress higher orders for energies below 100 eV.

Optical components which are illuminated directly by synchrotron light in a vacuum of 10^{-6} Torr are, after a while, covered with a surface layer of cracked hydrocarbons. At DESY intensity near the carbon K edge (∿280 eV) goes down to stray-light level within a few days of operation. At energies below 100 eV intensity drops off considerably within a few months of regular operation. Needless to say, it is not wise to illuminate gratings directly. In a well designed instrument the first optical component should be easily replaceable without the need for too complicated adjustments.

3.1.4 Grazing incidence imaging

The optical components readily available for making grazing incidence instruments are plane and spherical gratings, plane and spherical mirrors. It is far more difficult to obtain torroid or off-axis paraboloid mirrors. Gratings ruled on surfaces of the latter kind are not easily obtained but have been made[13].

Surface roughness does not appear to constitute a more serious problem than in the normal incidence region. The optical path difference between the reflection from hills and valleys is proportional to cos α where α is the angle of incidence. This factor approximately compensates for the decrease in wavelength in the grazing incidence region.

Imaging conditions for mirrors and gratings if not found in the literature (e.g. Samson[8], Beutler[14]) are obtained in a straight forward manner using geometrical optics for simple cases, or Fermat's principle for more tedious applications.(One special warning should be given in this context: a plane grating has imaging properties unlike those of a plane mirror.)

3.1.5 Mechanical problems

Precise and complicated motions under high vacuum conditions are not without problems. Any spectrograph mounting has, therefore, to be judged for the complexity of its moving parts. In a vacuum of 10^{-6} Torr techniques are possible which are not ideal but can simplify many mechanical problems considerably. Small epoxy-resin insulated motors and most types of potentiometers can be operated inside the vacuum. (If they need grease they should be washed and regreased with a diffusion pump oil or molybdenum sulfide powder.) If rubber o-rings and direct rotary feed-throughs are anyhow used such practice also appears to be tolerable. The devices mainly serve to move slits and to make final adjustments to optical components under operational conditions. (The main wavelength drive usually needs more sophisticated motors which cannot be operated under vacuum conditions.)

Care has to be taken to prevent hydrocarbons from diffusing into the accelerator by using low-conductance clean vacuum sections between the monochromators and the synchrotron. Moreover, implosion safety valves should be installed. One disadvantage of having hydrocarbons in the vacuum - even in small amounts - is that it leads to contamination of the optical surfaces (see section 3.1.3). At storage rings like DORIS having 100 to 1000 times higher intensity such techniques will not be tolerated. A new generation of bakable UHV monochromators with original gratings free from epoxy resin will be necessary.

3.2 Monochromator mountings

3.2.1 General remarks

Figures 5-7 give a survey of nine different types of monochromators which, to the author's knowledge, have been used either in conjunction with synchrotron radiation or are under construction. Some types have been abandoned again because of the introduction of more convenient instruments. Nevertheless, with the special requirements of UHV at storage rings some of the simpler arrangements could find renewed interest. It is not intended to give a complete discussion of these instruments here. The principle of operation, without any mathematics and without very many details of the technical realization, will be explained. A comparison between the instruments is given in an accompanying table (Table 1).

3.2.2 Plane grating monochromators

Figure 5a shows one of the simplest possible instruments[10,15,16]. It has the advantage of having only one reflecting surface, a plane grating. (At DESY it was necessary to avoid direct illumination of the grating by preceding the grating with a grazing reflection from a plane mirror.) Measurements which do not need high resolution like the reflectivity curves of Fig. 4 were obtained using a 600 lines/mm grating with a resolution of approximately 1:50 with 1 mm slits. The angle of incidence is variable if the grating can be rotated. Higher orders can be suppressed by a proper choice of this angle for different wavelength regions.

The instrument shown in Fig. 5b, designed at the Tokyo synchrotron[17], uses a plane grating and a spherical focussing mirror. The grating is rotated by small angles so that the sum of entrance and exit angles is fixed. The exit beam is spatially fixed which is a great advantage. With one spherical mirror two different arrangements are possible (only one of them is drawn). With different values for the sum of entrance and exit angles the two arrangements yield the same position of the exit beam. The authors report considerable contributions of stray-light at short wavelengths. Suppression of higher orders works only in a limited range.

The instrument in Fig. 5c was designed for use at the DESY synchrotron[18]. It uses a plane mirror, a plane grating and a paraboloid for focussing. The motion of the pre-mirror and the grating is fairly complex. In its simplest mode of operation the pre-mirror travels along the incident beam and rotates at the same time in such a way as to illuminate the grating. Simultaneously the grating rotates so that it remains parallel to the pre-mirror. Zero order emerges parallel to the incoming beam while light at a fixed angular separation from the zero order beam is accepted by the collimator-slit-system. The wavelength change is favourable for the suppression of higher orders since the longer wavelengths are taken at the steep angles. Indeed with a 1200 lines/mm grating and the other parameters properly chosen higher order light can be efficiently suppressed over the whole range of operation. Moreover this instrument is set up to always operate at the blaze maximum independent of wavelength. With additional "non-parallel" modes of operation the DESY instrument covers the energy range 15 - 280 eV. The fixed exit beam has an intensity maximum around 100 eV with a resolution of 1:400 to 1:800. Among other influences the width of the electron beam in the synchrotron is the limiting factor for the resolution.

3.2.3 Rowland mountings

Figure 6 gives four different versions based on the idea of the Rowland arrangement: entrance slit, grating and exit slit are all located on the Rowland circle. In principle, the Rowland arrangement is capable of yielding the optimum resolution, focussing errors being small[8,14].

The usual way to illuminate a conventional Rowland monochromator[2,4-6,19] with synchrotron light is a focussing pre-mirror as shown in Fig. 6a. The second order focussing error of a spherical mirror is

$$\Delta s = 3/2\ w^2/R \tag{2}$$

where $\pm w$ is the illuminated width, R the radius of curvature and Δs the increase in size of the focus. This limits the useful width of the bundle accepted by the monochromator. If, e.g, we take a slit width of 10 µm, R = 10 m, the grazing angle of incidence being 0.1 rad (∿6°), then the focal length will be 50 cm and the useful width of the bundle 3 mm (w = 15 mm).

At high energy synchrotrons only the arrangement shown in Fig. 6a , where the high energy beam does not intersect the Rowland circle, is acceptable. The disadvantage of this instrument is the travelling exit slit. Apart from a few exceptions mainly absorption measurements with the samples in front of the monochromator are possible. The version having a photographic plate as the detector, which is bent along the Rowland circle, is also extremly useful for such measurements. The Rowland instrument can be operated down to fairly short wavelengths (∿10 Å), a region still neglected in present day research. Unlike classical sources astigmatism does not pose problems when using synchrotron radiation. Rowland monochromators are in operation at every synchrotron laboratory.

The instrument shown in Fig. 6b was constructed by Codling and Mitchell[20] at Reading and used at Glasgow and Daresbury. It combines the advantages of a Rowland mounting with the property of having a fixed exit beam. Entrance and exit slits are fixed while the grating slides along the Rowland circle. The directions of the incoming and outgoing beams are changed by a rotating mirror-slit-combination. A forth mirror (not in the figure) is needed to illuminate the entrance slit. A disadvantage of the present arrangement lies in the considerable contribution of higher order radiation since the instrument passes the longer wavelength at more grazing angles of incidence. It has to be tested if this can be improved by a reversal of the direction of light (negative orders).

The instrument shown in Fig. 6c is a double-Vodar mounting under construction at the Stoughton storage ring[21]. The two spherical gratings (FG) together with the entrance slit of the second sub-instrument (exit slit of the first one) are connected rigidly on a bar . This unit is constrained in such a way that the exit slit and the second grating move on straight lines which meet at the position of the ultimate exit slit. The focussing mirror and the first entrance slit move together along the incoming beam so that the first grating is always illuminated. The two gratings need to have the same number of lines/mm but not necessarily the same curvature. The two Rowland sub-instruments operate in tandem yielding a fixed exit beam. The unpredictable aspect of this instrument lies in the gratings one of which is used in negative order. It will be very interesting to see the resulting spectra.

The instrument shown in Fig. 6d is under construction at the Bonn synchrotron[22]. The original idea was to restrict the number of reflections to two. It is not possible to generate a fixed exit direction of the beam but the position of the exit slit is fixed. The torroid mirror moves along the incoming beam and rotates at the same time. Simultaneously the coupled entrance slit-grating unit undergoes a complicated motion. The coupled motion is determined by the following constraints: 1. the Rowland condition has to be fulfilled and 2. the torroid mirror has to illuminate the grating with its focus being at the entrance slit. In instruments using a torroid mirror the "vertical" focussing is only fulfilled approximately. The instrument is intended for application with photoelectron spectroscopy. More details on this instrument are given in another paper (Thimm) at this symposium.

3.2.4 Non-Rowland monochromators

The principle of two further instruments using the electron beam as the entrance slit but concave gratings for focussing instead of mirrors is sketched in Fig. 7. Figure 7a shows how it is possible to change the alignment of a conventional Rowland instrument in such a way that it could be used without an entrance slit[2,11]. The focal curves for the illumination of a grating with parallel light are lemniscates (Beutler[14]). The grating of a Rowland monochromator can be tilted so that the path of the exit slit (originally moving on the Rowland circle) intersects the focal curve (lemniscate) at a wavelength position where optimum resolution is desired. This arrangement was previously used by the DESY group. It yields high intensity because the light undergoes only a single reflection but again it is problematic to illuminate the grating directly at synchrotrons having a high energy component of the spectrum.

Recently Ederer and Madden[13] have built an instrument with only a single optical element but still having a fixed exit beam (Fig. 7b). With the special geometry at the NBS synchrotron they could show that combinations of entrance angles and exit angles exist (in negative order) where a slight rotation of the grating causes only second order focussing errors. They were able to obtain a grating ruled on a torroidal surface thereby achieving a nearly stigmatic focus. A detailed report on the experiences with this instrument has still to come before one can judge its perspectives.

4. Crystal monochromators

4.1 General remarks

The region where crystal diffraction can be used to monochromatize synchrotron light extends in principle up to wavelengths around 100 Å. High absorption of crystal materials, however, makes gratings more advantageous for most applications down into the 10 - 20 Å region. Up to now crystal spectrometers are used or planned for usage only in a few cases: A crystal monochromator operating around 10 Å equipped with quartz, gypsum and mica crystals was used at the Frascati synchrotron[23,24]. A quartz crystal monochromator operating at a fixed photon energy of 1600 eV for XPS spectroscopy is presently being tested at DESY and a quartz monochromator operating in the 1 - 3 Å region is used for diffraction experiments on biological objects at DESY[25]. The author is not aware of any other activities with crystal monochromators at the moment.

One of the reasons for the limited interest in the x-ray region arises from the fact that only a few of the accelerators used at present emit light in this spectral regime while all of them can be used at longer wavelengths. Moreover, only if the gain in intensity is more than an order of magnitude does it become interesting to switch from handy x-ray tubes to complex synchrotrons. Originally, Parratt[26] (1959) gave optimistic estimates leading him to the conclusion that a high energy synchrotron equipped with a focussing or a two-crystal spectrometer was up in intensity by a factor of 10^2 as compared to characteristic conventional radiation. In the meantime, x-ray tubes were improved from 1 kwatt up to 100 kwatt. Moreover, the geometry chosen in Parratt's estimates appears to be unrealistic for practical applications (30 m rather than 3 m distance from the source). In order to make an exact comparison and to find out whether an effort with synchrotron radiation is worthwhile or not one needs to look into the details of a given experiment and perhaps do some preliminary tests. With the construction of high intensity storage rings such as DORIS the situation might change considerably (see Fig. 1).

4.2 Double crystal monochromator

Since the bremsstrahlen continuum of conventional tubes is down by four orders of magnitude compared to characteristic lines absorption spectroscopy should be worth trying. A double crystal monochromator[27] in which the two crystals undergo a coupled motion, as shown in Fig. 8a, gives a fixed exit beam. Efficiencies of crystals are usually higher than reflectivities of coatings in the soft x-ray region. The resolution of such an instrument would be limited by the angular width of the synchrotron light; the second crystal mainly serves to deflect the beam. A resolution of ∿0.5 eV could be obtained at 1600 eV. With two crystals in the antiparallel position[27] much higher resolution could be obtained at the cost of intensity and a more complicated scanning motion. By using synchrotron light admixing of higher order radiation will result which cannot occur in classical applications when the voltage of the x-ray tube is properly chosen. If non-photographic detection is applied different orders should be separable due to different amplitudes of the signals. With photographic registration reflections from mirrors at well chosen glancing angles are needed to eliminate higher orders[24,28].

4.3 XPS monochromator

A crystal monochromator for a fixed photon energy (1600 eV) was installed and is presently being tested by P. Rabe at DESY with the aim of investigating photoelectrons excited by monochromatic radiation[29] (XPS, ESCA). In this case focussing of the monochromatized radiation into a spot of as small a size as possible is a decisive factor. A grazing paraboloid mirror could serve this purpose (Fig. 8b) because of the extremely small angular spread of the synchrotron beam. A high quality paraboloid, however, is difficult to obtain. Another suggestion is to bend the crystal in a direction perpendicular to that of dispersion. This idea goes back to early mica spectrometers[27]. Bending in this direction has a negligible influence on the resolution (0.05 eV for the DESY instrument). Focussing in the direction of dispersion is then achieved by reflection from a cylindrical parabola bent from a glass plate. When in full operation this instrument will allow for a direct comparison of intensities with existing classical XPS-spectrometers.

4.4 Monochromator for diffraction work

Another type of experiment is performed by using synchrotron light for diffraction studies in the 1 - 3 Å region[25]. Such an experiment was developed and tested at DESY on behalf of the European Molecular Biology Laboratory Project by a team from the Max-Planck-Institut für medizinische Forschung in Heidelberg (Barrington Leigh, Holmes, Rosenbaum, Witz). It is intended to investigate ordered biological objects (muscles etc.) before they decompose. In a future program time-resolved conformational changes of the specimen are to be studied. First results give the diffraction pattern of a flight muscle from the water bug in a relaxed and in a rigor state. Although the angular resolution was considerably increased the pictures were obtained in 5 minutes compared to 5 hours with conventional techniques. Of course, a similar technique could also be applied for other fields of research e.g. low-angle scattering.

The instrument used does not need extremely good energy resolution. Focussing in one direction can, therefore, be achieved by bending the crystal. For a crystal having a surface parallel to the reflecting planes monochromatic focussing could only be achieved at a distance equal to that between crystal and source (40 m at DESY). Guinier showed how to make these distances unequal[28] by cutting the surface of the crystal at an angle to the reflecting planes (8^{o} 30' in this case). This in itself is not sufficient to obtain the desired focal length of 1.5 m. Additional bending (radius 30m) was applied; this results in a wavelength spread of $\Delta\lambda \sim 3 \cdot 10^{-3}$ Å. The instrument is sketched in Fig. 8c. Focussing in the perpendicular direction (not shown in Fig. 8c) is achieved by a mirror bent to a radius of 1000 m giving total reflection at a glancing angle around 4 mrad. The spot at the film has a size of about 250 μm in both directions. The gain in speed of more than two orders of magnitude over classical instruments is due to the increase in brightness[30] of the synchrotron source. Its brightness, however, decreases with a half width of less than a milliradian in the vertical direction. Therefore, the advantages of the synchrotron source come into play mainly with experiments which in principle cannot accomodate large bundles of radiation.

It appears to be obvious that monochromators for the x-ray region will be built as integrated parts of the whole experiment rather than as separate universal devices.

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Table 1: Survey on grazing incidence monochromators

figure	type	accelerator	number of reflections	grating	exit beam	resolution
5a	plane grating	DESY (Nowak et al.)	1	plane	moving	low
5b	plane grating	INS-SOR (Miyake et al.)	2	plane	fixed	medium
5c	plane grating	DESY (Kunz et al.)	3	plane	fixed	medium
6a	Rowland	all labs.	2	spherical	moving	high
6b	Rowland	Glasgow/DNPL (Codling et al.)	4	spherical	fixed	high
6c	Rowland-Vodar	Stoughton (Pruett et al.)	3	spherical (two)	fixed	high
6d	Rowland	Bonn (Thimm et al.)	2	spherical	fixed slit moving angle	high
7a	parallel illumination	DESY (Haensel et al.)	1	spherical	moving	medium
7b	distant source	NBS (Ederer et al.)	1	torroidal	fixed	medium

Figure Captions

Fig. 1: Useful intensity obtained with an aperture of 2 cm x 2 cm at laboratory distance from the source (40 m) for an existing synchrotron (DESY) and an electron-positron storage ring under construction (DORIS). The cut-off parameter λ_c is marked.

Fig. 2: Relative distribution of intensity into different diffraction orders[9] as a function of wavelength for two different gratings (Bausch and Lomb replica), the theoretical blaze-wavelength is indicated.

Fig. 3: Typical spectrum for the grazing incidence region for instruments with fixed angle of incidence. This spectrum was obtained with a low resolution instrument[10] of the type Fig. 5a. Intensity between zero order and the steep increase at ∿200 eV allows for an estimate of stray-light.

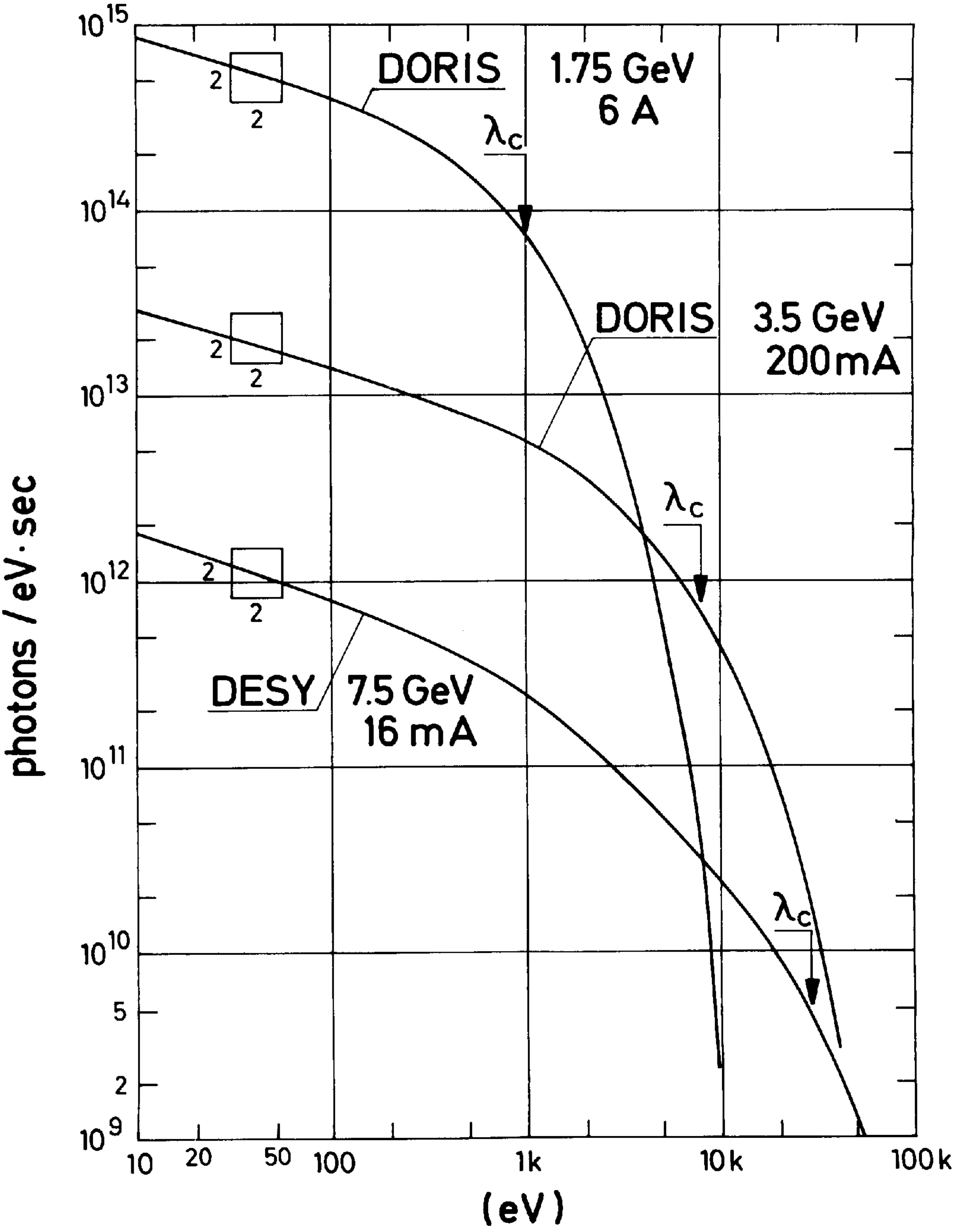
Fig. 4: Reflectance of Pt for different angles of incidence as a function of photon energy in s-polarization (after Römer[10]).

Fig. 5: Three types of plane grating monochromators. The scanning motion of the elements is indicated. PG = plane grating, PM = plane mirror, FM = CM = focussing mirror. Synchrotron light is coming from the left.

Fig. 6: Four types of monochromators which operate according to the Rowland principle. FG = focussing grating, other abbreviations as in Fig. 5.

Fig. 7: Two types of focussing grating non-Rowland instruments, F = focussing curve, A = approximation to F, R = Rowland circle. Other abbreviations as in Figs. 5 and 6.

Fig. 8: Three types of crystal monochromators. C = crystal, FM = focussing mirror, S = sample, PH = photographic plate.



photons / eV · sec
10^15
10^14
10^13
10^12
10^11
10^10
5
2
10^9
10
20
50
100
1k
10k
100k
(eV)
DORIS 1.75 GeV 6 A
DORIS 3.5 GeV 200 mA
DESY 7.5 GeV 16 mA
λc
λc
λc
2
2
2
2
2
2

Fig. 1

Fig. 2

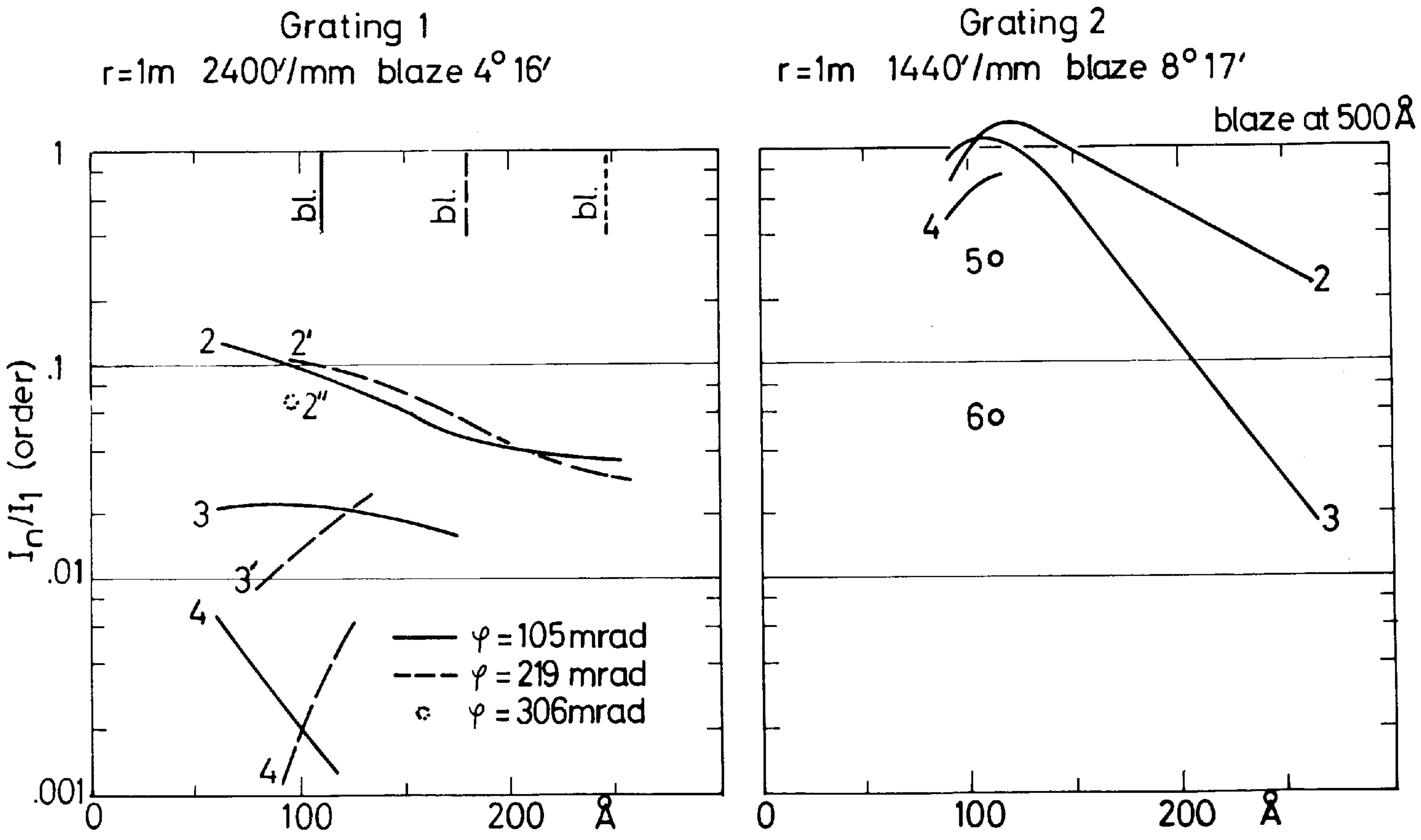
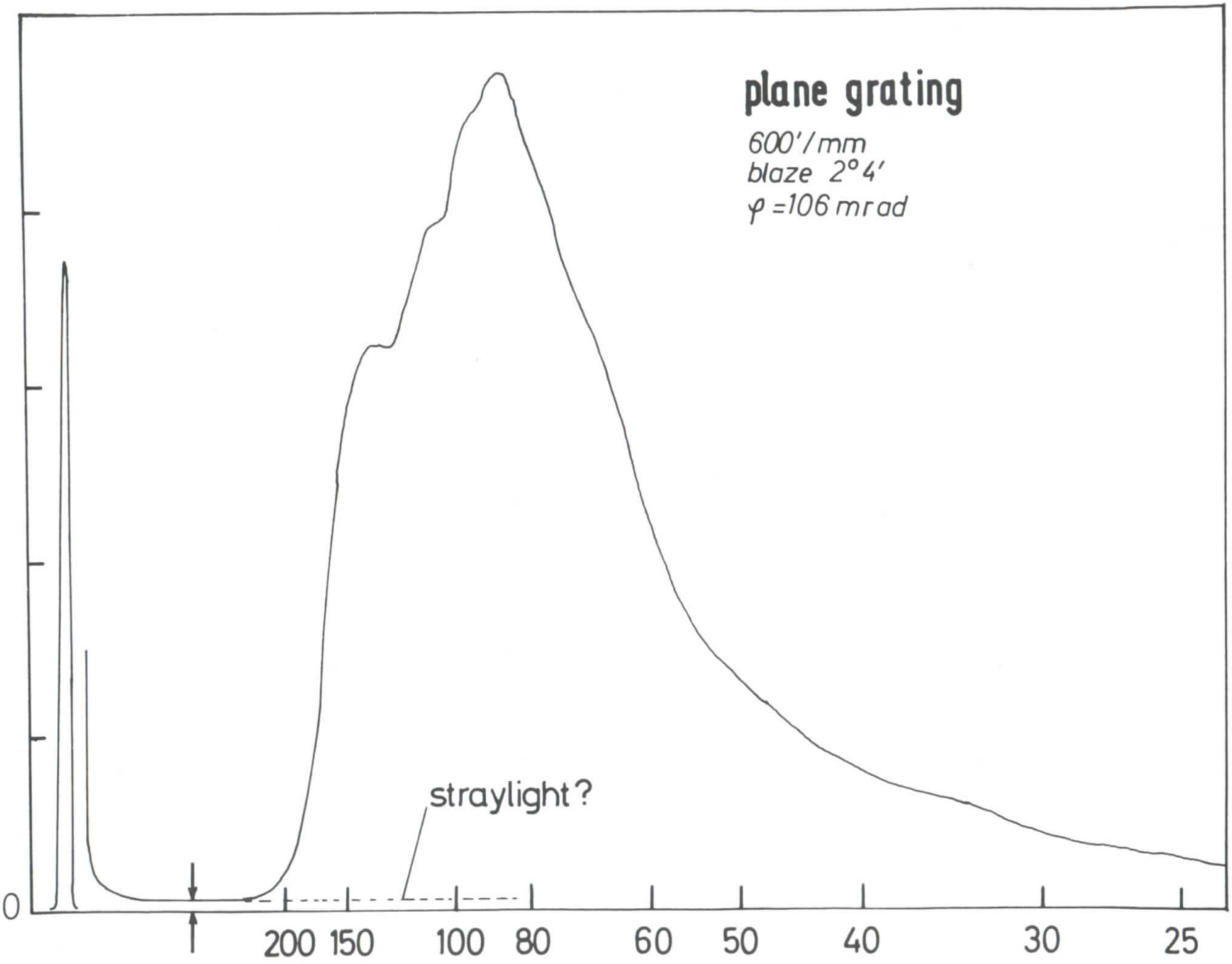

Grating 1
r=1m 2400'/mm blaze 4° 16'
Grating 2
r=1m 1440'/mm blaze 8° 17'
blaze at 500 Å
I_n/I_1 (order)
1
.1
.01
.001
0
100
200
Å
bl.
bl.
bl.
2
2'
2"
3
3'
4
4
φ = 105 mrad
φ = 219 mrad
φ = 306 mrad
2
3
4
5
6

Fig. 3


plane grating
600'/mm
blaze 2°4'
φ =106 mrad
straylight?
0
200
150
100
80
60
50
40
30
25

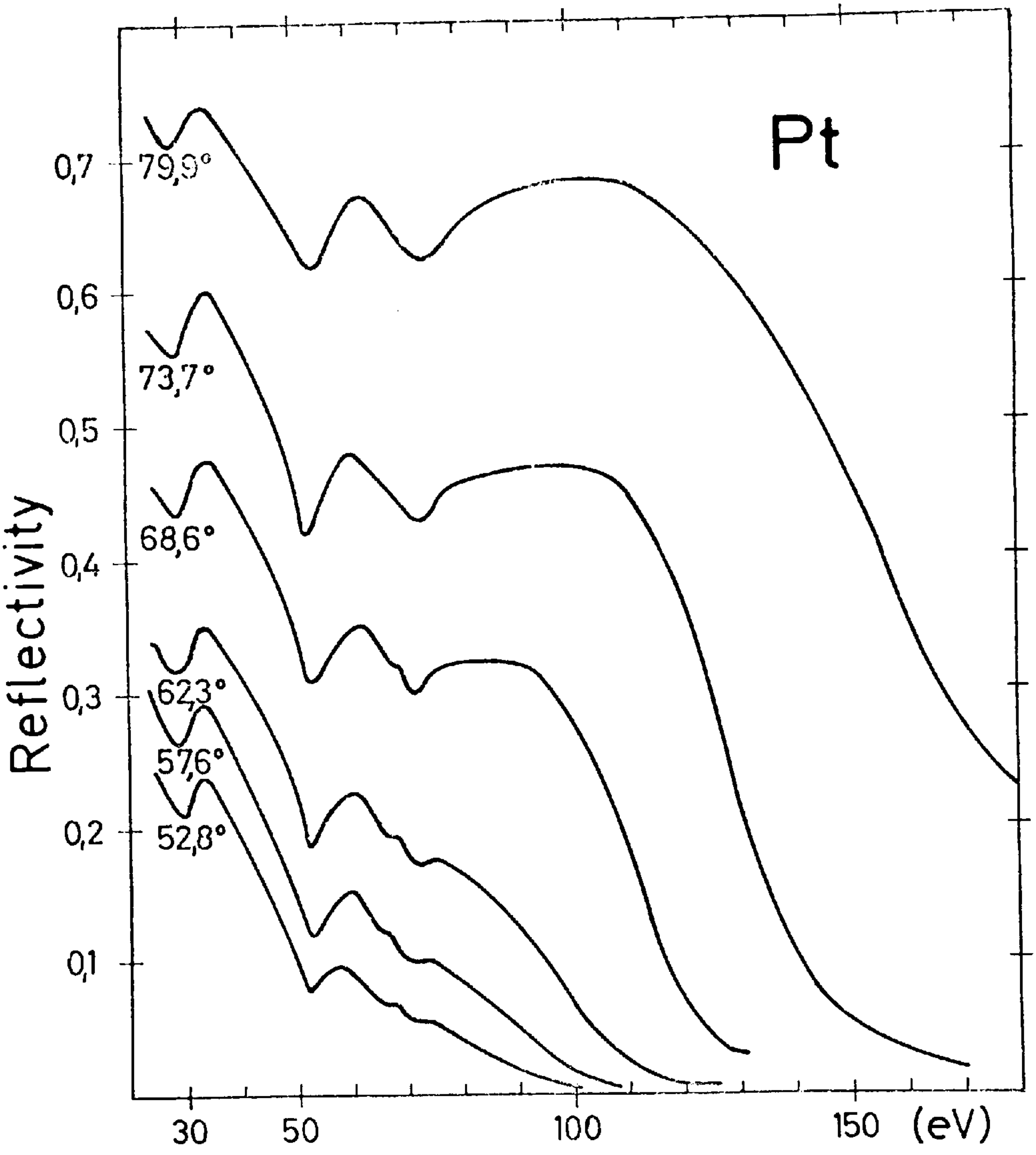

Pt
Reflectivity
0,7
0,6
0,5
0,4
0,3
0,2
0,1
79,9°
73,7°
68,6°
62,3°
57,6°
52,8°
30
50
100
150
(eV)

Fig. 4

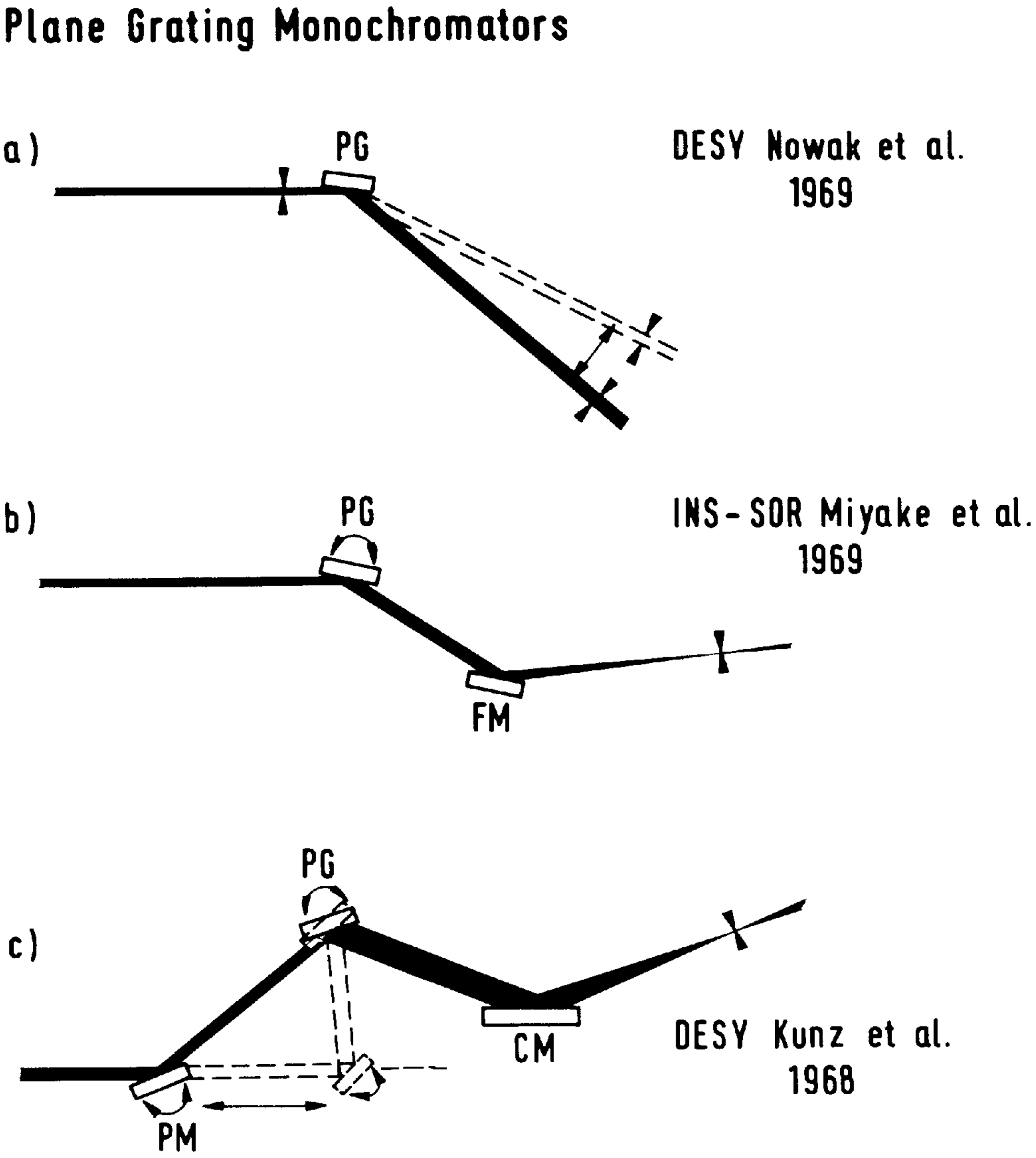
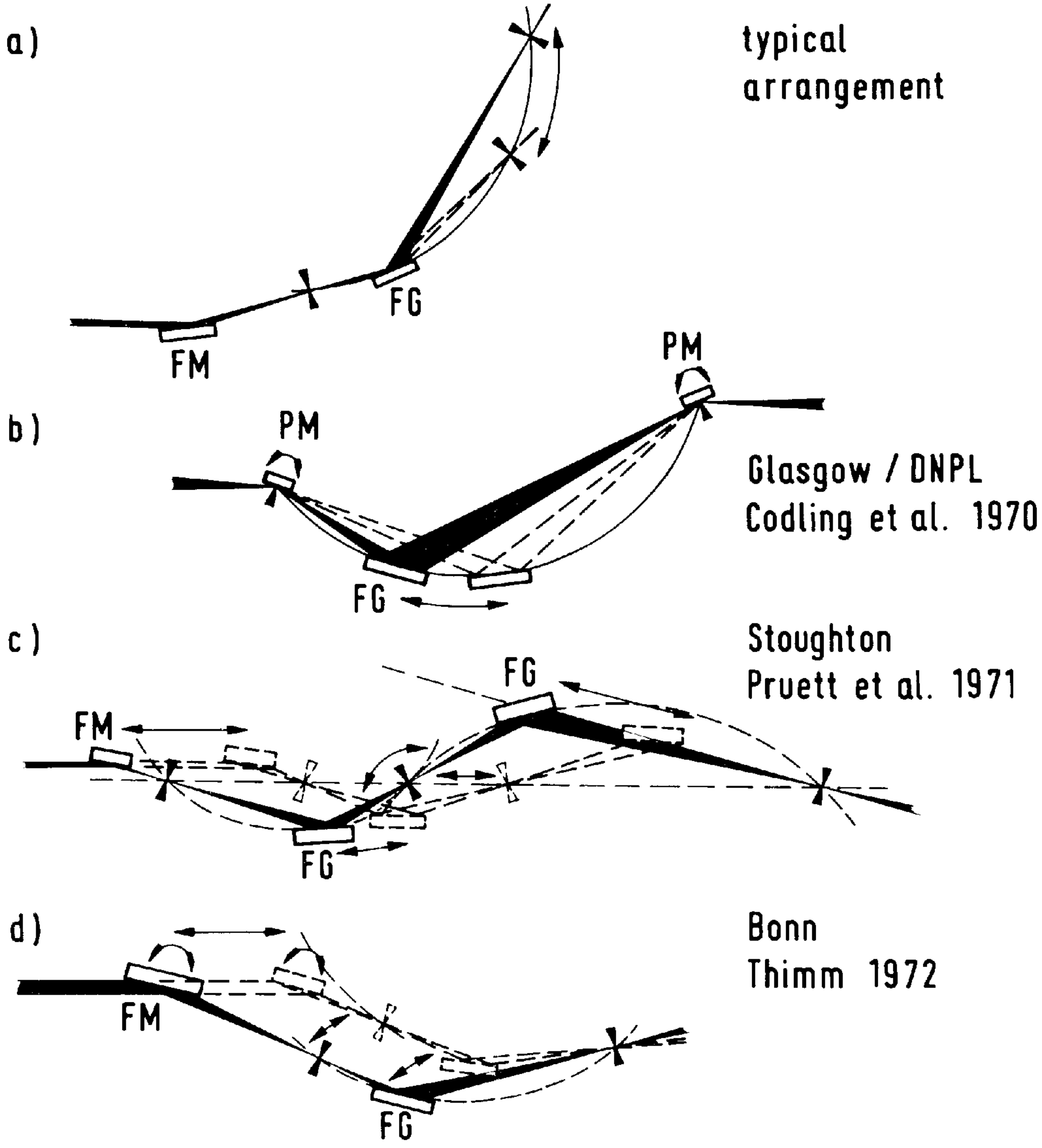

Plane Grating Monochromators
a)
PG
DESY Nowak et al.
1969
b)
PG
FM
INS-SOR Miyake et al.
1969
c)
PG
CM
PM
DESY Kunz et al.
1968

Fig. 5

Rowland Monochromators



a) typical arrangement

b) Glasgow / DNPL
Codling et al. 1970

c) Stoughton
Pruett et al. 1971

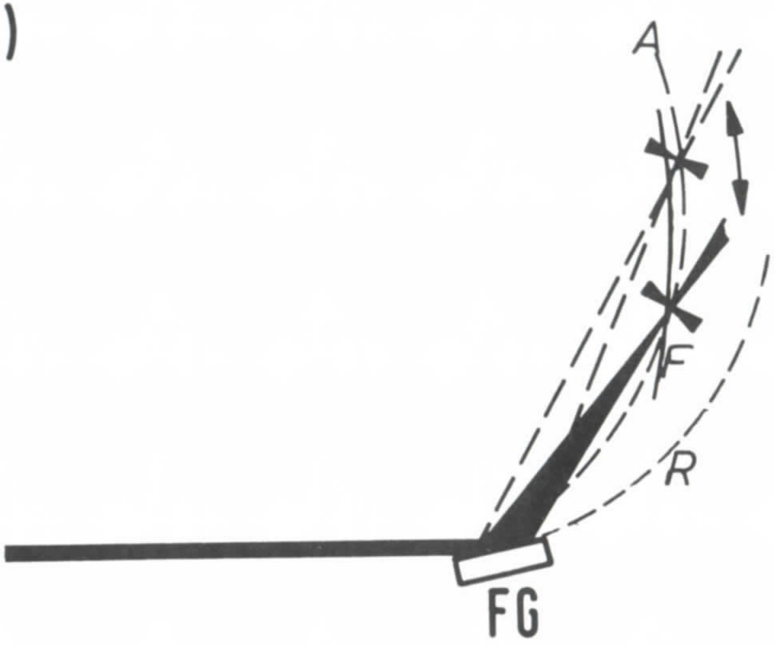
d) Bonn
Thimm 1972

Fig. 6

Non Rowland Monochromators

a)

DESY 1967



b)

NBS
Ederer et al. 1972

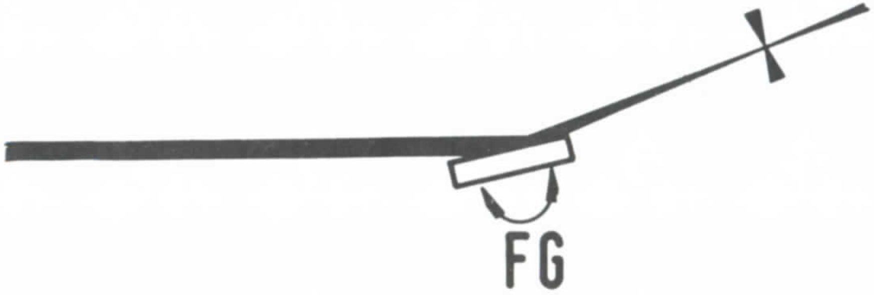


Fig. 7

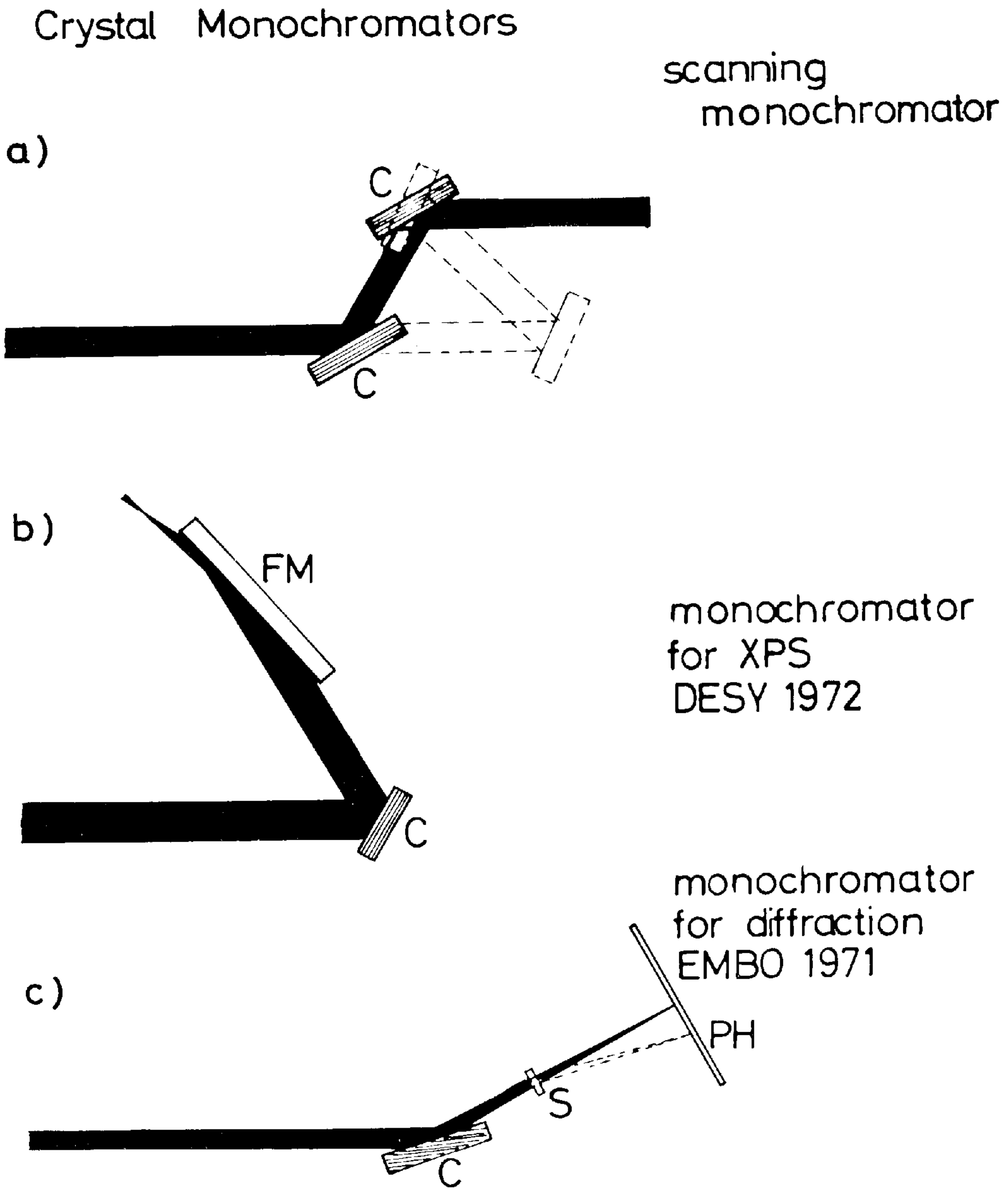

Crystal Monochromators
scanning monochromator
a)
C
C
b)
FM
monochromator for XPS DESY 1972
C
monochromator for diffraction EMBO 1971
c)
PH
S
C

Fig. 2