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Improvement in laser-plasma analysis makes it necessary to perform accurate calibration in the soft X-ray range. For this purpose we have mofified a plasma Focus device (27 kJ, 40 kV, 400 kA) in order to enhance its soft X-ray emission : a hollow anode is used to prevent hard X-ray bremsstrahlung emission and a lot ot filling gases are chosen for their characteristic lines in the keV and sub-keV range (Ne, Ar, O, N, CH_4). These emissions have been absolutely measured with an X-ray bolometer and can be used directly or indirectly (in the fluorescent mode : Mg Kα at 1.254 keV) for X-ray calibration of varicus diagnostics. Some detector calibrations in pulsed regime (10 ns) are presented (Films, solid state PIN diodes, CCD arrays).

INTRODUCTION

Improvement in laser plasma diagnostic analysis makes it necessary to perform accurate calibration mainly in the soft X-ray range.

For this purpose we have developed and tested a modified plasma Focus device in order to enhance its soft X-ray emission. This emission can be calibrated with the help of bolometric measurements /1/ and then used for various detector calibrations.

I. SOFT X-RAY SOURCE

A 27 kJ, 40 kV, 400 kA plasma Focus discharge has been modified by hollowing out the copper central anode in order to minimize its hard X-ray bremsstrahlung. Instead of hydrogen or deuterium gases previously used in such devices we have chosen as filling gases rare gases such as Ar, Ne, Kr or others (O, N, Air, CH_4).

A schematic of the device is shown in figure 1.

The temporal, spatial and spectral characteristics of the soft X-ray emission are presented in the figure 2 using a neon gas discharge.

The time duration (Fig. 2a) was measured by means of a fast plastic scintillator (NE 111) coupled with a fast visible diode. The signal was recorded on a digital oscilloscope TEKTRONIX 7912 with a 700 Mhz bandwidth amplifier and a protection from visible light is obtained with a 25 μm thick beryllium window. In this way, we can obtain information about X-rays above 800 eV.

The figure 2b shows the X-ray emission region recorded on a Kodak SB2 X-ray film using a pinhole camera 1 X magnification. The pinhole was 100 μm in diameter and a beryllium foil, 12.5 μm thick is used as a visible light filter. The X-ray emission is located on the axis of the gun at the end of the anode. We have observed from shot to shot a high stability in the range of 1 mm.

The X-ray spectrum of the emission was analysed with a flat crystal (Tl AP) spectrograph and recorded an Kodak SB2 X-ray film. The figure 2c shows the optical density profile of the film obtained from two different shots. The X-ray energy is radiated in spectral lines (H or He-like ion) of neon and for a great part from the He-like ion free-bound emission. The spectrograph has no entrance slit and so we can control that the spectrally resolved emission region is filament shaped.

The energy radiated into X-rays was measured by means of an X-ray bolometer developed in our laboratory for laser plasma X-ray calorimetry /1/.

The X-ray energy emitted from neon gas discharge is about 20 Joules/4Π. A similar X-ray yield in H and He ions emission lines is obtained with other filling gases except for argon. In this case we observed no heating of the bolometer in the 3-4 keV emission range (He and H-like argon ions) while an important yield (250 J/4Π) was measured in the sub-keV range.

II. PRINCIPLE OF DIAGNOSTIC CALIBRATIONS

For diagnostic calibrations reported here, the filling gas of the discharge is neon at 1.4 mbar pressure. The X-ray flux incident on the detector is absolutely calibrated by means of a direct calorimetric measurement using X-ray bolometers /1/.

A. DIRECT CALIBRATION

The experimental spectrum shown in figure 2c can be modified by putting a thin Al filter before the detector. In this case the major part of the X-ray energy is located between the He-like free-bound limit of neon ions (1.2 keV) and the K-edge energy of the Al filter (1.56 keV). Taking into account the X-ray yield, the filter transmission, the minimal approach distance (10 cm) and the bolometer sensitivity (0.1 mJ/cm^2), the aluminium thickness must be kept below 10 μm. With such a low thickness, the X-ray flux level is too much high for any detector to be calibrated (film, PIN diode, CCD array). An acceptable flux ($10^{-7}J/cm^2$) leads to place these detectors at long distances (10 m) or to increase the foil thickness in front of the detector. The first solution implies the use of a cumbersome vacuum tube now under construction, while for the second we need a more precise spectrum knowledge :

For this purpose we have drawn up a simple theoretical simulation of the X-ray emission of the neon ions (fig. 3). In this simulation the exponential decrease is characteristic of the plasma electron temperature kT and must be deduced from experimental measurements by a pseudo Ross filter technique.

Using two balanced filters (Be-25 μm and Al-9 μm) we have calculated from this spectrum the ratio of the transmitted energies for different plasma temperatures. In figure 4 we present this ratio dependance over the plasma temperature. It can be very simply measured with two bolometers for each shot and the corresponding temperature can be deduced from figure 4.

With this spectral knowledge we can perform a direct calibration of the detector with an Al filter thicker than the one used for bolometric measurement. As a disadvantage of this direct calibration it must be noticed that, with thicker Al filters, the high energy tail of the spectrum increases at the expense of the energy part below the K-edge.

B. FLUORESCENT MODE CALIBRATION

In order to prevent this trouble (X-ray spectra not roughly monochromatic on the detector to be calibrated) we have operated with the help of the fluorescent radiation of a chosen target. Having a too low sensitivity the bolometer can not measure the fluorescent radiation itself but allows us to determine the X-ray flux and its spectral distribution on the fluorescent target. As shown in figure 5 the assessment of the total energy incident on the fluorescent target is achieved by means of a bolometer filtered by the same foil as the target. The spectral distribution (plasma temperature) is obtained with the use of the second bolometer as explained previously. Hence the fluorescent flux on the detector can be calculated numericaly from the fluorescent yield, the geometrical conditions and the X-ray absorption coefficients.

For this calibration experiments a 50 μm thick magnesium foil was used as a fluorescent target with a mainly Kα emission line at 1.254 keV. According to the exponential deacrease of the spectrum other fluorescent targets can be used : Al (Kα = 1.487 keV) and Si (Kα = 1.730 keV). A softer X-ray emission can be reached with a CF2 target (F Kα at 677 eV).

III. RESULTS

In the direct calibration mode we have tested X-ray sensitivity of films and PIN diodes. For film calibration we have used the same filter as for bolometer measurements (Al 9 μm) so the X-ray flux was too high (~ 10^{11} photons/cm^2) at the maximum available distance (~ 80 cm). As a result we have obtained saturated optical densities ($d>3$). For PIN diodes (quantrad 125) a thicker Al filter (50 μm) was used to reach an acceptable signal level. In this case, as mentionned previously, the high energy tail led to a discrepancy between experimental and theoretical calibrations. For 7.10^8 photons of 1.4 keV incident on the detector the calibration was 3.10^{-17} C/keV to be compared with the theoretical value of 10^{-17} C/keV (3.67 eV for each electron-hole pair formation and calculated transmission of the entrance window).

For Mg-Kα fluorescent radiation calibration we have measured X-ray sensitivity of films, PIN diodes and CCD arrays. The response of both Kodak DEF and SB2 films exposed at the same shot is shown in figure 6. For PIN diode we have performed ten shots at the mean level of 10^8 photons/cm^2 at 1.254 KeV. We have obtained $(6.5 \pm 1.5)10^{-18}$ C/keV in better agreement with the calculated value.

A CCD array (Thomson TH7882 - front illuminated) has been tested with the same radiation. For this CCD a signal level of about 30 mV was found for a 3.10^8 photons/cm^2 incident X-ray flux.

FIGURES CAPTIONS

FIGURE 1 : schematic of the pulsed soft X-ray source

- a) electrical diagram
- b) view of the coaxial gun

FIGURE 2 : characteristics of the X-ray emission

- a) temporal
- b) spatial
- c) spectral

FIGURE 3 : theoretical simulation of the spectral emission of a neon gas discharge - α represents the contribution of the line with respect to the continuum emission.

FIGURE 4 : calculated ratio of the transmitted energies (Be/Al) versus electron plasma temperature.

FIGURE 5 : Experimental set up for fluorescent mode calibration

FIGURE 6 : Calibration of Kodak X-ray film with a pulsed Mg Kα Fluorescent radiation at 1.254 keV

- a) direct exposure film
- b) SB2
- c) K.M.S. Inc. measurement /2/ with DEF X-ray film on a continuous X-ray source

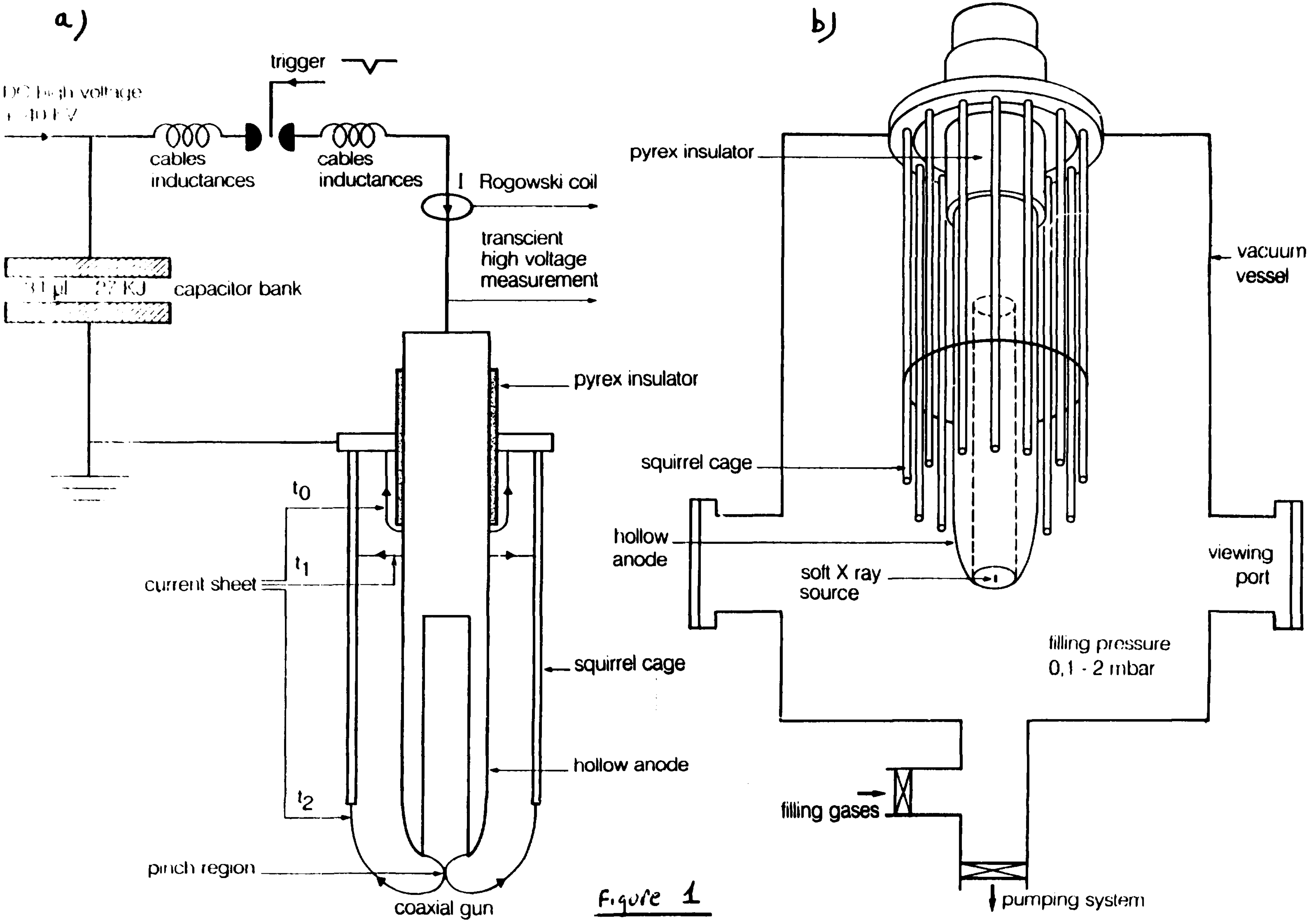

a)
trigger
DC high voltage
+ 40 kV
cables
inductances
cables
inductances
I
Rogowski coil
transcient
high voltage
measurement
31 µf 27 KJ
capacitor bank
pyrex insulator
t_0
t_1
current sheet
squirrel cage
hollow anode
t_2
pinch region
coaxial gun
b)
pyrex insulator
vacuum
vessel
squirrel cage
hollow
anode
soft X ray
source
viewing
port
filling pressure
0,1 - 2 mbar
filling gases
pumping system

Figure 1

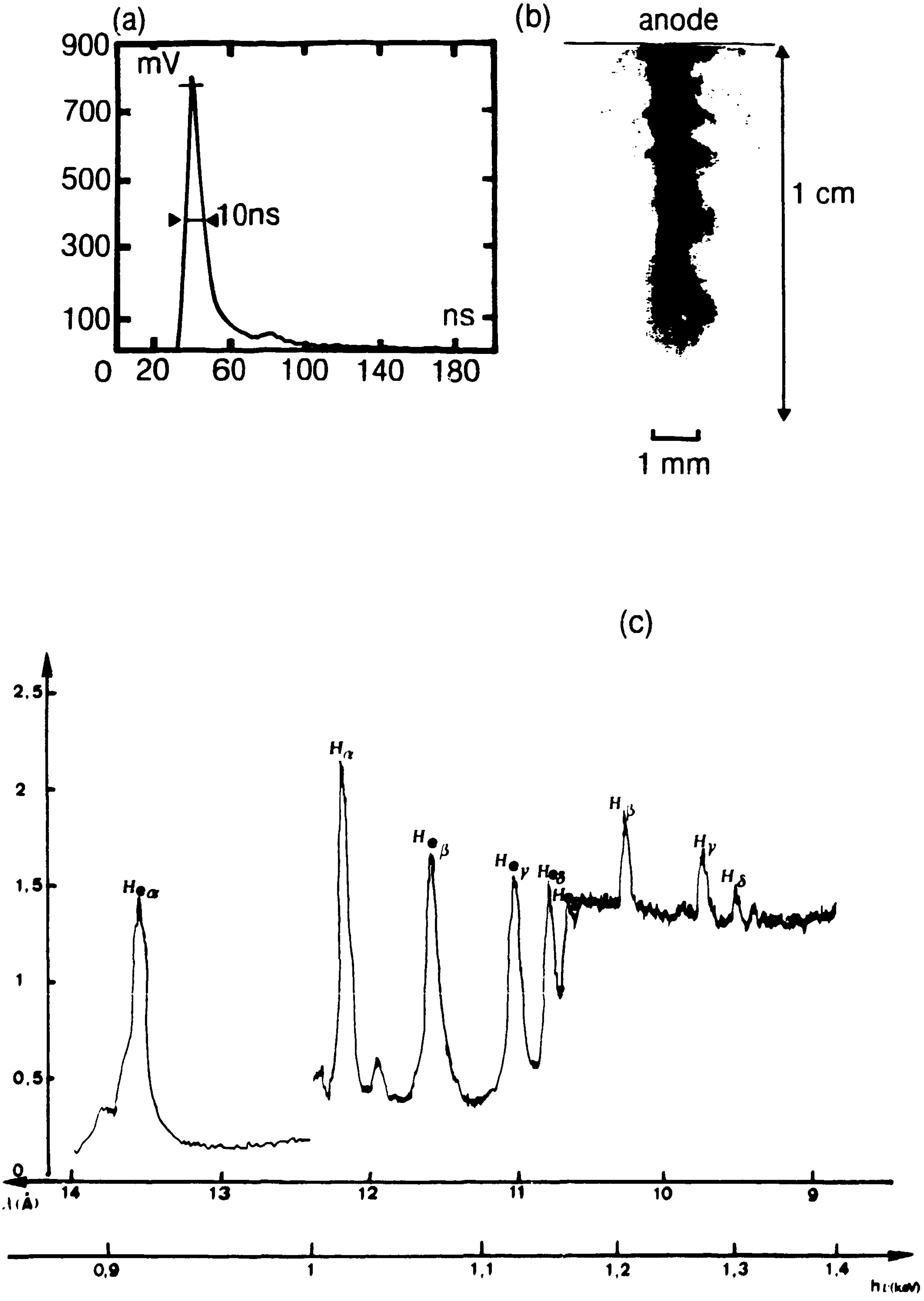
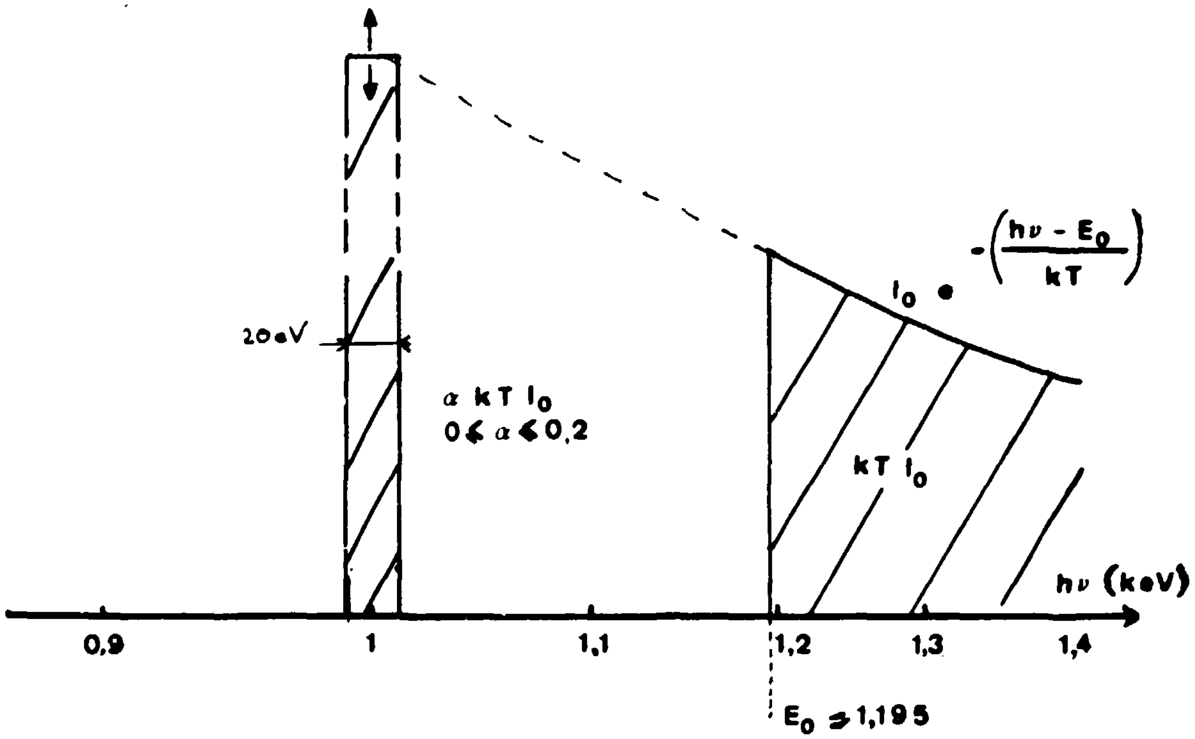

(a)
900
mV
700
500
300
100
10ns
ns
0
20
60
100
140
180
(b)
anode
1 cm
1 mm
(c)
2,5
2
1,5
1
0,5
0
Heα
Hα
Heβ
Heγ
Heδ
Hβ
Hγ
Hδ
λ(Å)
14
13
12
11
10
9
0,9
1
1,1
1,2
1,3
1,4
hν(keV)

Figure 2



20eV
$\alpha\, kT\, I_0$
$0 \leqslant \alpha \leqslant 0{,}2$
$I_0\, e^{-\left(\frac{h\nu - E_0}{kT}\right)}$
$kT\, I_0$
$h\nu$ (keV)
0,9
1
1,1
1,2
1,3
1,4
$E_0 \simeq 1{,}195$

Figure 3

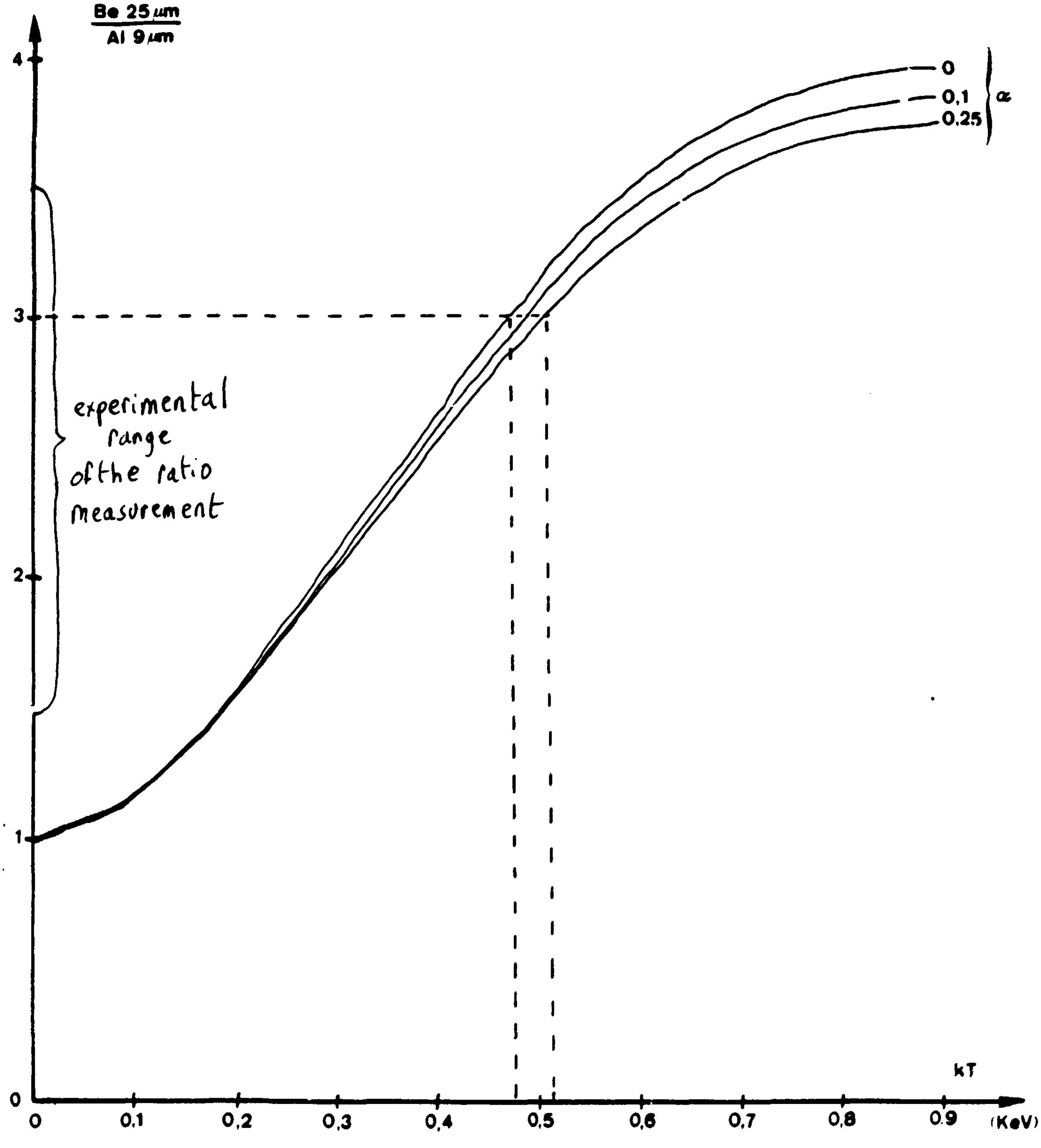

Be 25 µm
Al 9 µm
4
3
2
1
0
experimental range of the ratio measurement
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
kT
(KeV)
0
0,1
0,25
α

Figure 4

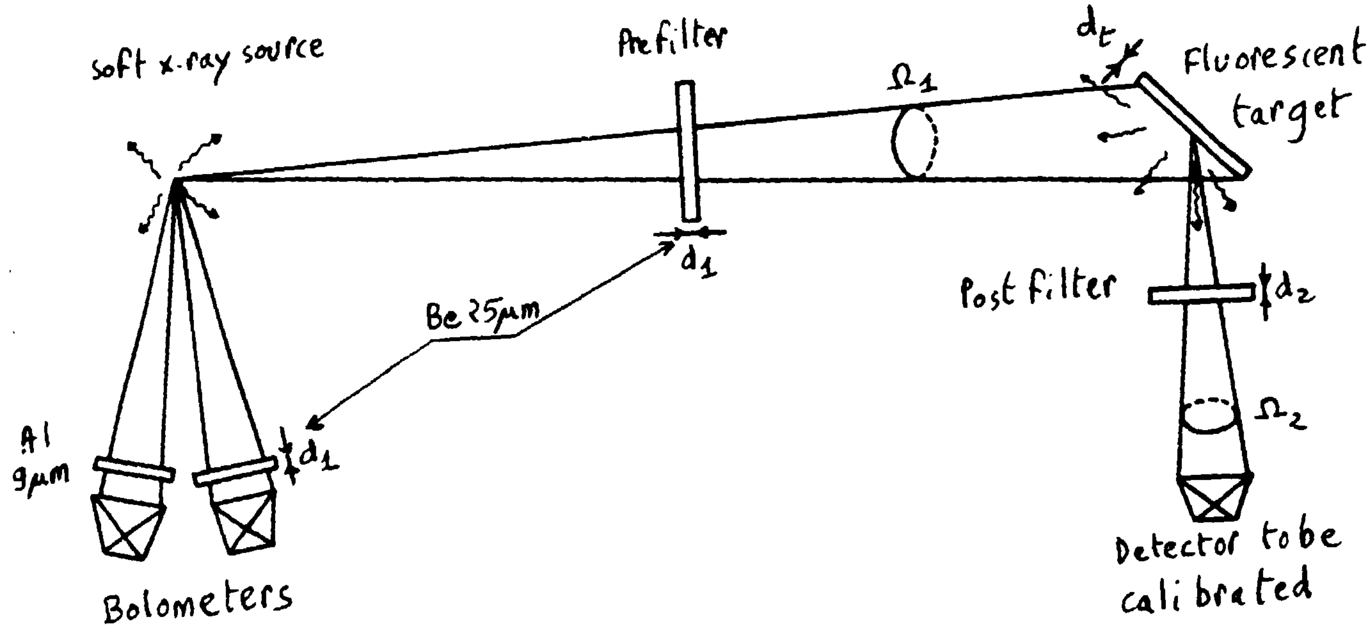

soft x-ray source
Prefilter
d_1
Ω_1
d_t
Fluorescent target
Post filter
d_2
Ω_2
Detector to be calibrated
Be 25µm
Al 9µm
d_1
Bolometers

Figure 5

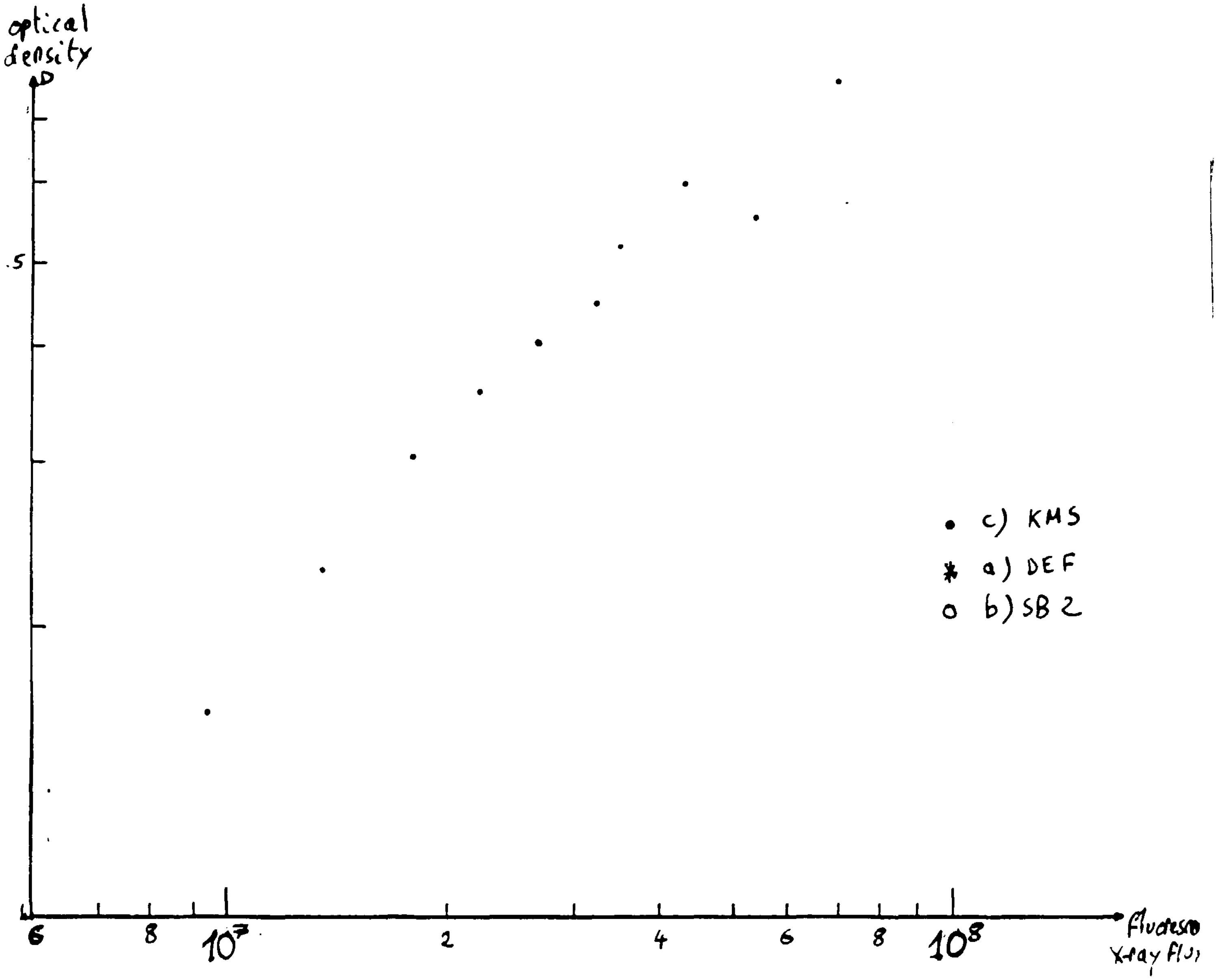

optical density
D
.5
6
8
10^7
2
4
6
8
10^8
fluences
X-ray flux
● c) KMS
✱ a) DEF
○ b) SB 2

Figure 6

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