NBS TECHNICAL NOTE 594-12

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Optical Radiation Measurements:

The Translucent Blurring Effect— Method of Evaluation and Estimation

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.

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Jack J. Hsia

Optical Physics Division
Institute for Basic Standards
National Bureau of Standards
Washington, D.C. 20234

U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, *Secretary*

Edward O. Vetter, *Under Secretary*

Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

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P R E F A C E

This is the twelfth issue of a series of Technical Notes entitled OPTICAL RADIATION MEASUREMENTS. The series will consist primarily of reports of progress in, or details of, research conducted in radiometry, photometry and spectrophotometry in the Optical Radiation Section and the Radiometric Physics Section of the Optical Physics Division.

The level of presentation in OPTICAL RADIATION MEASUREMENTS will be directed at a general technical audience. The equivalent of an undergraduate degree in engineering or physics, plus familiarity with the basic concepts of radiometry and photometry [e.g., G. Bauer, Measurement of Optical Radiations (Focal Press, London, New York, 1965)], should be sufficient for understanding the vast majority of material in this series. Occasionally a more specialized background will be required. Even in such instances, however, a careful reading of the assumptions, approximations, and final conclusions should permit the non-specialist to understand the gist of the argument if not the details.

At times, certain commercial materials and equipment will be identified in this series in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

Any suggestions readers may have to improve the utility of this series are welcome.

Henry J. Kostkowski, Chief
Optical Radiation Section
National Bureau of Standards

Jack L. Tech, Chief
Radiometric Physics Section
National Bureau of Standards

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THE TRANSLUCENT BLURRING EFFECT — METHOD OF EVALUATION AND ESTIMATION

Jack J. Hsia

The translucent phenomenon which causes flux loss in spectrophotometric measurements is described. Methods for mathematically evaluating the flux loss are examined, and experimental methods using laser and conventional light sources are described. A widely used Vitrolite glass standard is employed to demonstrate the error estimation and correction.

Key Words: Blurring effect; edge loss, error analysis; flux loss; plastics; reflectance; scattering; spectrophotometry; translucency; transmittance; Vitrolite glass.

1. INTRODUCTION

Improving the accuracy and usefulness of spectrophotometric measurements made throughout the scientific and industrial community is a fundamental purpose of the spectrophotometry group of the Radiometric Physics Section of NBS. Increasing numbers of spectrophotometric measurements are being made on plastic materials, and these measurements are usually based on white glasses as measurement standards. In view of this, the possibility of measurement error caused by flux loss resulting from the translucency [1,2,3][1] of the specimens deserves close study. Such a measurement error can occur because of improper design of the instrument being used, or by not fully recognizing the limitations of the instrument. Even when the source of error is recognized, its magnitude is sometimes underestimated.

The purposes of this Technical Note are to call attention to this often ignored error, to derive the mathematical equations and perform measurements in order to evaluate the magnitude of this error, to describe procedures for estimating the error, and to recommend methods for reducing the error.

A general equation for flux loss and equations for special cases are derived in Part 2. Several experimental setups and methods are presented in Part 3 to demonstrate how to measure the flux loss and to show what is to be expected for its magnitude. Part 4 contains a case study describing the simulation of an actual instrument and shows how to predict flux loss by using the general equation and experimental results from Parts 2 and 3, respectively. The conclusions and recommendations are given in Part 5.

2. THE TRANSLUCENT BLURRING EFFECT

The reflection from a sample such as plastic or white glass can be divided into two parts: the surface reflection and the body reflection. As incident radiation strikes the surface of the sample, it moves from the air into a medium of higher index of refraction. At the point where the radiation passes from one medium to another, a fraction is reflected (Fresnel reflection). More than ninety percent of the incident flux passes through the surface and into the sample. A small fraction of this radiation is absorbed in the material and a large fraction of this radiation escapes after being randomly scattered within the material. The main part of the radiation which is reflected from the sample travels this route. One can gain an intuitive feeling for this process by thinking of the radiation in terms of photons. As is indicated in figure 1, a photon that enters at point P, moves from one scattering point to another until at last it emerges at another point, p. The probability that the photon will emerge at a particular point decreases with the distance of that point from the point of entry, but there is a finite possibility that the photon might emerge at a relatively large distance from P. We will call the tendency for point irradiation of a sample to produce reflected radiation from a large area of the sample the "translucent blurring effect", and we will call the portion of the radiation that emerges from the surface of a sample beyond the edge of the sample mask the "flux loss", since it does not contribute to the response of the receiver.

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[1]Figures in brackets indicate the literature references at the end of this paper.

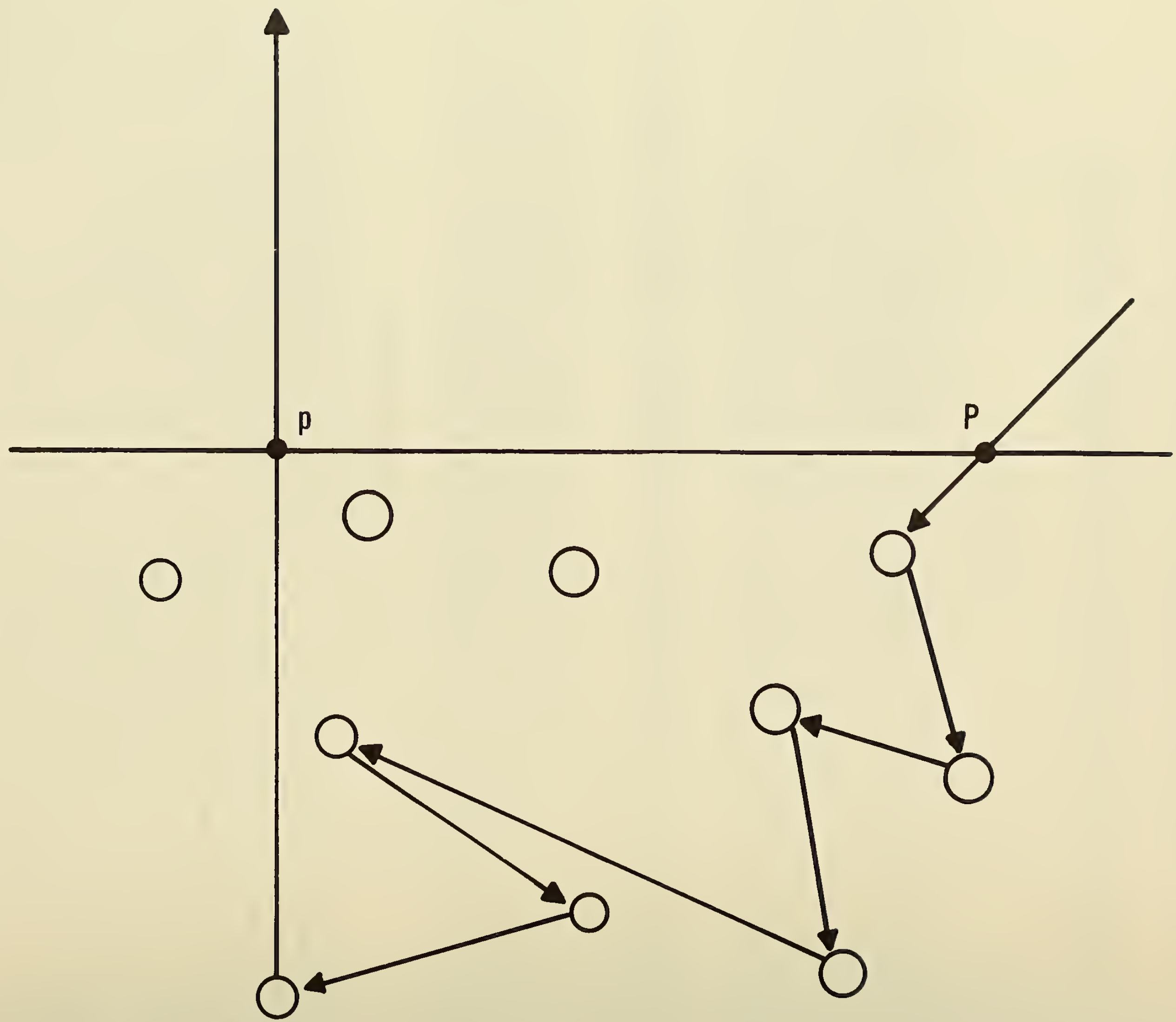

Fig. 1. Path of a photon in a diffuse reflector.

2.1 General Mathematical Equation

Since details are important to a thorough analysis of a measurement, a complete definition of the measurement will be provided here. The approach to describing the measurements and the notation used is given in detail in an NBS Technical Note [4].

The measurement to be defined will be restricted to flat samples and the directions and locations involved in the measurement will be described in terms of a plane which coincides with what, on a macroscopic scale, would be regarded as the surface of the sample. In this way the complications of describing the microscopic variations in the shape of the "real" surface are avoided. Only steady-state measurements on nonfluorescing samples will be considered here, so that the definitions will not be functions of time. For simplicity, the wavelength and polarization will not be explicitly indicated in the notation.

Under the foregoing conditions, the remaining parameters to be considered are geometrical, involving the irradiated and viewed areas and the directions and solid angles of irradiation and viewing. Refer to figure 2. The fraction received is defined as the ratio of the reflected flux that is detected by the receiver from the finite area of the sample inside the mask to the reflected flux that would be detected by the receiver from an infinitely large area of the same sample. The percent flux loss is one minus the fraction received, expressed as a percentage. A general expression for the fraction received can be written in terms of the geometrical parameters in the following form:

$$F = \frac{\int_{a\neq\infty}\int^3 LS_x R\vec{U}\cdot d\vec{A}\ d\Omega\ d\omega\ \vec{u}\cdot d\vec{a}}{\int_{a=\infty}\int^3 LS_x R\vec{U}\cdot d\vec{A}\ d\Omega\ d\omega\ \vec{u}\cdot d\vec{a}} \tag{1}$$

where $L = L(\vec{P},\vec{U})$ is the radiance input (incidence radiance), $S_x = S_x(\vec{P},\vec{U};\vec{p},\vec{u})$ is the scattering function of the sample, $R = R(\vec{p},\vec{u})$ is the response (responsivity of the detection system), $\vec{P}$ is a position vector denoting the point at which the radiation enters the surface, $\vec{U}$ is a unit vector indicating the direction of entry for the radiation, $d\vec{A}$ is an element of surface area at point $\vec{P}$ and $d\Omega$ is an element of solid angle in the direction of $\vec{U}$. The lower case variables $\vec{p}$, $\vec{u}$, $d\vec{a}$ and $d\omega$ have a similar meaning with respect to the radiation emerging from the surface. (The sumbol $\int^3$ is a shortened notation indicating integration with respect to dA, $d\Omega$ and $d\omega$, with each integral being taken over the full range of the corresponding parameter.) For highly collimated radiation striking a finite area of the sample, the radiance input can be written as

$$L = E(\vec{P})\ \delta(\vec{U}_0 - \vec{U})/\cos\Gamma_0 \tag{2}$$

where $\vec{U}_0$ is the direction of incidence, $\delta(\vec{U}_0 - \vec{U})$ is the Dirac delta function, Γ_0 is the angle between the normal to the surface and the direction of incidence, and $E(\vec{P})$ is the spectral irradiance at the point P where $E(\vec{P})$ is non-zero only over a finite area, i.e. the area being irradiated, and

$$\int q(\vec{U})\ \delta(\vec{U}_0 - \vec{U})\ d\Omega = q(\vec{U}_0) \tag{3}$$

where $q(\vec{U})$ is an arbitrary function of direction. In the case of a uniform and isotropic translucent sample, the amount of radiation emerging from a given point from the sample depends only on the absolute value of the displacement from the point of entry of the incoming radiation which causes it. In this case the scattering function can be expressed as

$$S_x = S_x(\Gamma_0;|\vec{p} - \vec{P}|,\ \vec{u}) \tag{4}$$

Further, for the case of viewing the sample by the receiver from one direction, the scattering function can be written as

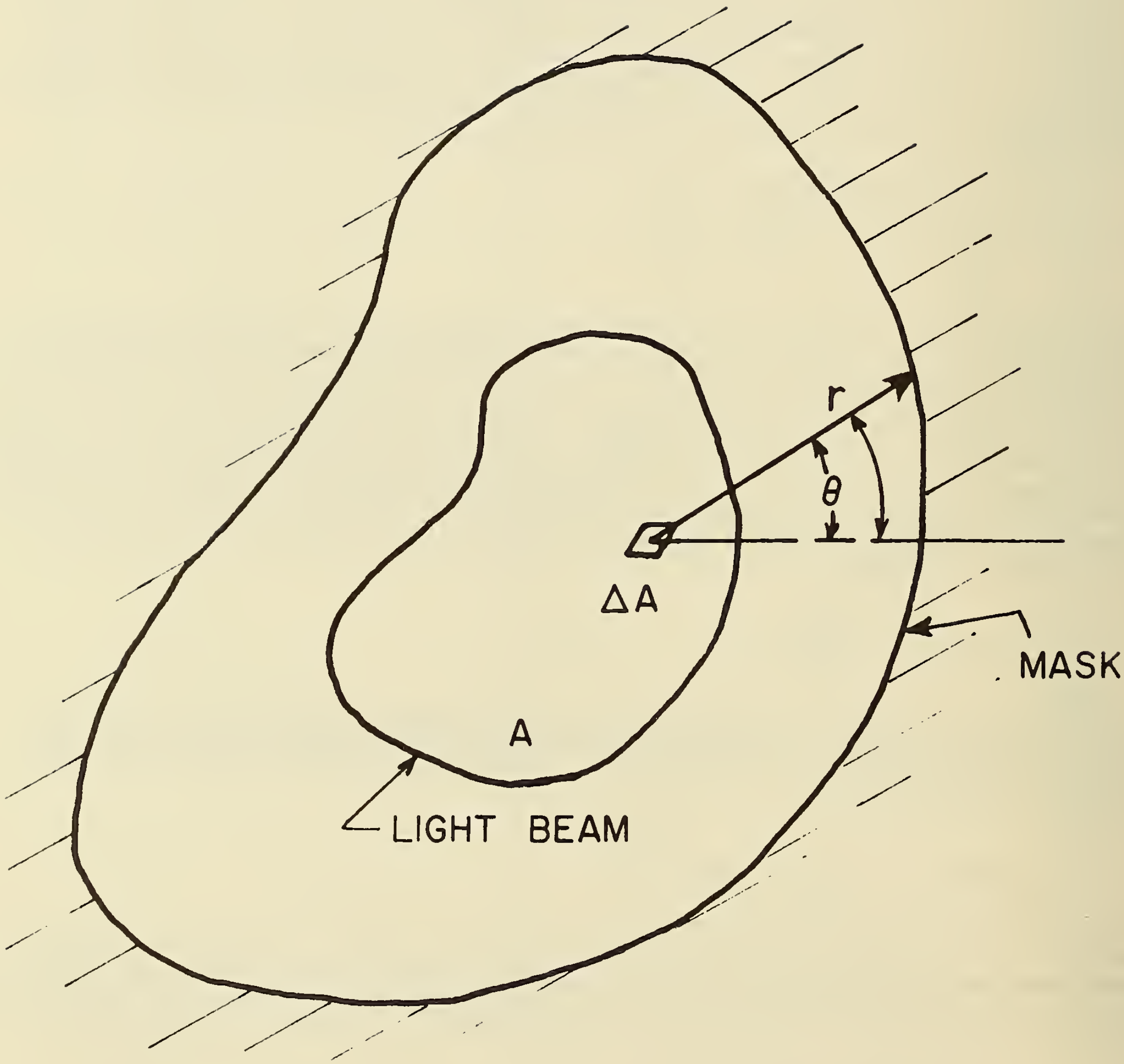

Fig. 2. A general sketch for describing the blurring phenomenon.

$$S_x = S_x(\Gamma_0; |\vec{p} - \vec{P}|, \gamma_0) \tag{4}$$

where γ_0 is the angle between the normal to the surface and the direction of incidence. In the ideal receiver, R is independent of position on the sample and is independent of direction of emergence, i.e. each photon of reflected radiation produces the same contribution to the instrument output, regardless of where it emerges or of the direction in which it emerges within the area and solid angle from which rays are within the beam accepted by the instrument. Thus

$$R \text{ is constant.} \tag{5}$$

Inserting equations (2) and (4) in the general expression (1) for the fraction received, one obtains:

$$F = \frac{\int_A E(\vec{P}) \int_{a\neq\infty} S_x(\Gamma_0; |\vec{p} - \vec{P}|, \gamma_0)\, da\, dA}{\int_A E(\vec{P}) \int_{a=\infty} S_x(\Gamma_0; |\vec{p} - \vec{P}|, \gamma_0)\, da\, dA} \tag{6}$$

where $\int_{a=\infty} S_x(\Gamma_0; |\vec{p} - \vec{P}|, \gamma_0)\, da = C$ is independent of A and can be taken out of the integral of A in the denominator. Expressing da in cylindrical coordinates, eq. (6) can be written as

$$F = \frac{\int_A E(\vec{P}) \int_0^{2\pi} \left[\frac{1}{C} \int_0^r S_x(\Gamma_0; |\vec{p} - \vec{P}|, \gamma_0)\, r dr \right] d\Theta dA}{\int_A E(\vec{P})\, dA} \tag{7}$$

or

$$F = \frac{\int_A E(\vec{P}) \frac{1}{2\pi} \int_0^{2\pi} f(r(\Theta))\, d\Theta dA}{\int_A E(\vec{P})\, dA} \tag{8}$$

where

$$f(r) = \frac{\int_0^r S_x(\Gamma_0; |\vec{p} - \vec{P}|, \gamma_0)\, 2\pi r dr}{\int_{a=\infty} S_x(\Gamma_0; |\vec{p} - \vec{P}|, \gamma_0)\, da} \tag{9}$$

where f(r) is the fraction received from a circular area with radius r. f(r), as a function of r, can be determined experimentally and some results are presented in Part 3. Once f(r) is known, eq. (8) gives the fraction received from any shape of area as long as r can be expressed as a function of Θ. For most of the shapes of area, it is generally difficult to perform the integration. For these cases eq. (8) can be written in terms of summations to perform computations on the computer.

$$F = \frac{\sum_A \left[E(\vec{P}) \frac{1}{2\pi/\Delta\Theta} \sum_0^{2\pi} f(r(\Theta)) \right] \Delta A}{\sum_A E(\vec{P})\, \Delta A} \tag{10}$$

2.2 Special Cases

The general equations expressed by eqs. (8) and (10) can be simplified in the special cases: (a) the incident flux at the sample port is uniform, (b) the sample port and light beam are circular, and (c) the light beam is misaligned.

2.2.1 Uniform incident flux

For uniform incident flux, the irradiance is independent of the position on the sample, i.e., $E(\vec{P})$ = constant. Equation (8) can then be simplified

$$F = \frac{1}{A}\int_A \left[\frac{1}{2\pi}\int_0^{2\pi} f(r(\Theta))\,d\Theta\right] dA \tag{11}$$

In order to discuss the next two special cases, the concept of the incident ring-shape beam should be mentioned here. Refer to figure 3a. Assume the incident beam is in the shape of a ring with width Δx and radius x and the ring is concentric with the sample port (or mask) which has a radius m. The fraction received in this area can be expressed as:

$$F_x = \frac{1}{2\pi x\Delta x}\left[\frac{1}{2\pi}\int_0^{2\pi} f(r(\Theta))\,d\Theta\right] 2\pi x\Delta x \tag{12}$$

$$F_x = \frac{1}{2\pi}\int_0^{2\pi} f(r(\Theta))\,d\Theta \tag{13}$$

or

$$F_x = \frac{1}{2\pi/\Delta\Theta}\sum_0^{2\pi} f(r(\Theta)) \tag{14}$$

where

$$r = (m^2 - x^2 + x^2\cos^2\Theta)^{\frac{1}{2}} - x\cos\Theta \tag{15}$$

2.2.2 Concentric circular incident beam and sample port (or mask)

Refer to figure 3a. For an incident beam with radius ℓ and sample port with radius m, eq. (11) can be written as:

$$F = \frac{1}{\pi\ell^2}\int_0^{\ell} F_x 2\pi x dx \tag{16}$$

or

$$F = \frac{1}{\pi\ell^2}\sum_0^{\ell} F_x 2\pi x\Delta x \tag{17}$$

2.2.3 Misalignment

Refer to figure 3b. When the center of the beam is misaligned and its distance from the center of the sample port is e, the fraction received can be expressed as

$$F = \frac{\int_0^{\ell+e} F_x g 2\pi x dx}{\int_0^{\ell+e} g 2\pi x dx} \tag{18}$$

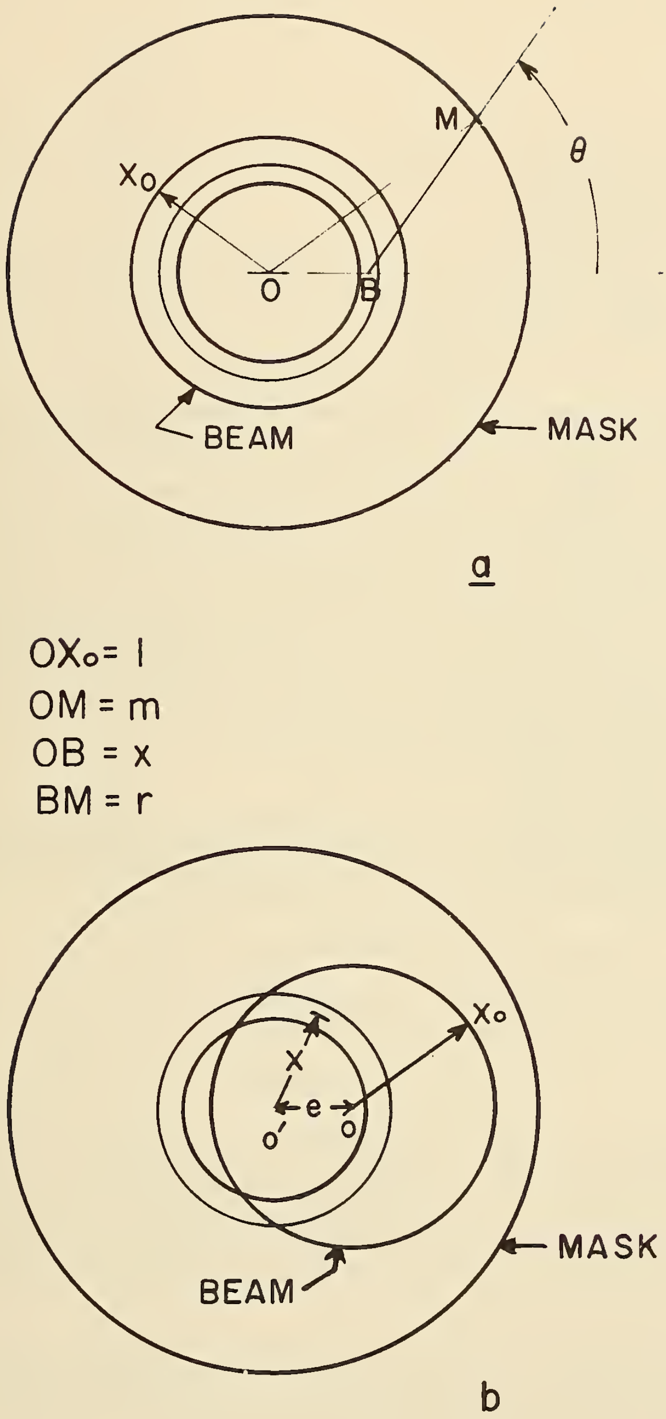

Fig. 3. A sketch for circular beam and mask
3a. Concentric
3b. Misaligned

or

$$F = \frac{\sum_{0}^{\ell+e} F_x gx}{\sum_{0}^{\ell+e} gx} \tag{19}$$

where

$$g = \frac{1}{\pi} \cos^{-1}\left(\frac{e^2 + x^2 - \ell^2}{2ex}\right) \tag{20}$$

is the fraction of the ring (with radius x and its center at the center of the mask) inside the boundary of the misaligned incident beam.

3. EXPERIMENTAL EVALUATIONS

There are two methods to study the translucent blurring phenomenon quantitatively. The first method is to use a radiation beam of finite size in an experiment to measure the flux from areas with different radius, reduce the data mathematically to the case for the beam of infinitesimal size, and then calculate cases of beams with other sizes by numerical integration. The second method is to use a beam with a very small diameter, such as a laser beam, and calculate cases of beams with other sizes by numerical integration which requires that a beam be divided into many small parts (or alternatively to use a large radiation beam viewed at a very small area). The first method calls for solving an integral equation first for its kernel and then re-integrating [5]. The second method is much simpler since an approximation to the kernel is obtained directly. It is valid as long as, during the numerical integration, the divided beam is not smaller than the beam size of the laser. The second method is used to determine the values of f(r) as defined in eq. (9). Using the second method measurements are made (a) with small radiation beam and large viewed area, and (b) with large radiation beam and small viewed area.

Since Vitrolite white glass has a stable reflectance and a very uniform surface, it has been used as a reflectance standard for commercial instruments and is also issued by NBS as a reflectance standard. For this reason an 11-mm-thick Vitrolite white glass sample is used to demonstrate the experimental methods for evaluating flux loss.

3.1 Small Radiation Beam and Large Viewed Area

A laser reflectometer was used [6]. Reflected fluxes with masks of different sizes in front of a Vitrolite glass sample were measured.

3.1.1 Instrument

The schematic diagram of the laser reflectometer is presented in figure 4. A He-Ne laser source is operated at 632.8 nm. An aperture stop with about 2 mm diameter is placed directly in front of the laser to block the scattered radiation surrounding the main beam. Further filtering is accomplished by letting the beam go through a spatial filter consisting of two quartz lenses and one 20 μm diameter pinhole. The pinhole can be adjusted in a plane normal to the beam. The first lens focuses the collimated laser beam onto the pinhole and the second lens converts the diverging beam into a collimated beam of about 0.7 mm radius.

The mirror chopper serves to reduce background noises by using synchronous amplifiers, as well as to modulate the final output from the detector by directing the reflected beam from the chopper into an averaging sphere and monitor detector. The main beam passes through a baffle to reduce stray light. The sample can be clamped on a sample holder with an opening of 19 mm radius. A mask can be placed in front of the sample surface. Six masks are available with opening radii of 1.6, 2.4, 3.2, 4.8, 6.4, and 7.9 mm.

Lead sulfide cells with sensitive area of 10 x 10 mm were used. The field of view of the sample detector just covers the opening of the sample holder. The signals from the

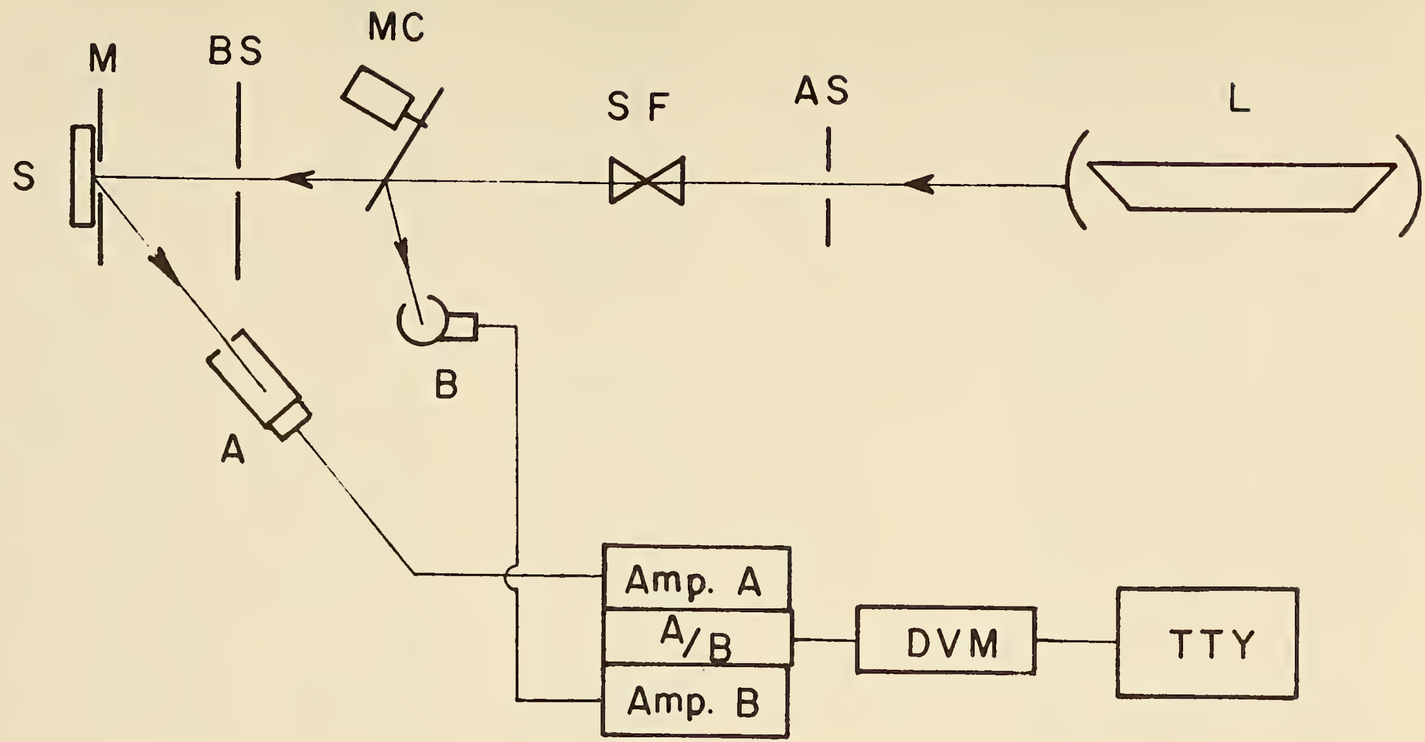

Fig. 4. The setup with small light beam and large viewed area. L = He-Ne laser; AS = aperture stop; SF = spatial filter; MC = mirror chopper; BS = baffle and stop; M = mask; S = sample; A,B = Detectors A and B; Amp. A,B = Amplifier A and B; A/B = ratiometer; DVM = digital voltmeter; TTY = teletypewriter.

detector A and the monitor detector B are amplified separately. The outputs of the two amplifiers are then fed into a ratiometer whose output is proportional to the ratio of the two inputs. The ratio signal is then fed into a digital voltmeter and recorded by means of a teletypewriter. The double-detector system ensures that the output from the digital voltmeter is independent of the drift of the laser-source output level.

3.1.2 Measurement and results

The flux reflected by a Vitrolite [7] glass sample, 76 × 76 mm and 11 mm thick, was measured with and without mask, with normal incidence and 45° viewing. All signals were corrected for the dark signal which is the signal when the laser source is blocked. The measuring sequence was designed to reduce the drift of the system [8].

The sample holder opening of 19-mm radius can be considered as a mask opening of infinite radius, since the difference in reflected fluxes for larger masks is undetectable. The fraction received was calculated by taking the ratio of the signal when measured with the mask to the signal without the mask. The fraction received is plotted in figure 5 as a function of the radius of the mask opening and the value of 1 when the radius is 19 mm. The solid curve was determined by fitting the data by the method of least squares to an exponential function. The choice of the exponential function is empirical. For this Vitrolite glass sample (11 mm thick) measured with 0.7 mm radius laser beam, the fraction received function, f(r), is as follows:

$$f(r) = 1 - \exp(br + cr^2 + dr^3) \tag{21}$$

where r is in mm, b = −0.939, c = 0.0774, and d = −0.00299.

3.2 Large Radiation Beam, Small Viewed Area

3.2.1 Instrument

The fraction received by using a large radiation beam and small viewed area was measured on a separate setup. The sketch is shown in figure 6. A tungsten light source and two lenses are used to produce a large light spot on the sample surface. The central area of 0.1 mm diameter of the light spot is viewed by a photometer. Different sizes of light spots on the sample surface are produced with an aperture turret containing six apertures with opening radii of 1.5, 2.5, 3.5, 5.0, 8.0 and 12.0 mm. For the setup in figure 6a, lens L2 produced a one to one magnification. The radius of the light spot thus could be varied from 1.5 to 12.0 mm.

Wavelength changes are made either with different interference filters in the source system or with broadband filters in the photometer. Five interference filters, with 20 nm bandpass and with peak wavelengths at 450, 500, 550, 600, and 650 nm, are used. Three broadband filters are used in the photometer: a blue filter with peak transmittance at 450 nm and bandpass of 60 nm, a photopic filter with peak at 550 nm and bandpass of 100 nm, and a red filter with peak at 600 nm and bandpass of 70 nm.

3.2.2 Measurement and results

At each wavelength the reflected fluxes from the Vitrolite glass sample (11 mm thick) and white paint sample were measured at each aperture setting. The fraction received is calculated by taking the ratio of the signal when measured on the Vitrolite sample by that measured on the white paint sample. All such ratios are normalized to the ratio at 12 mm aperture radius. The white paint sample is chosen because its reflectance is independent of wavelength in the visible range and it has very slight translucency compared with the Vitrolite sample. Taking the ratio of the signals from the Vitrolite sample to that of the white paint sample eliminates flux differences caused by changing the filter or size of the aperture. The results are plotted in figure 7. The fraction received shows a definite wavelength dependency. At longer wavelengths the fraction received is smaller. In other words, the translucent blurring effect is larger at longer wavelengths. Measurements made

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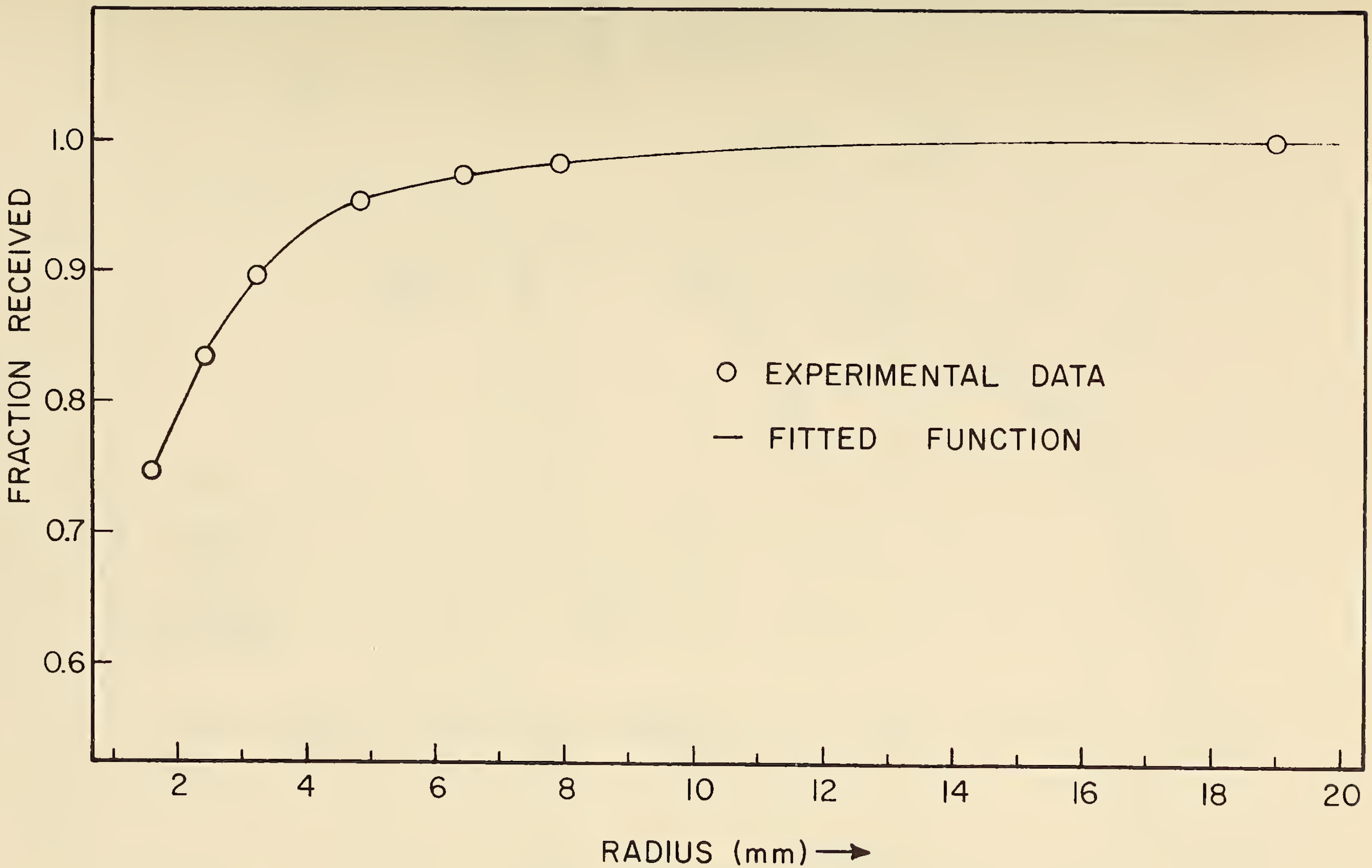


Fig. 5. Results of the blurring experiment on Vitrolite glass sample with the radius of the laser beam ≃ 0.75 mm.

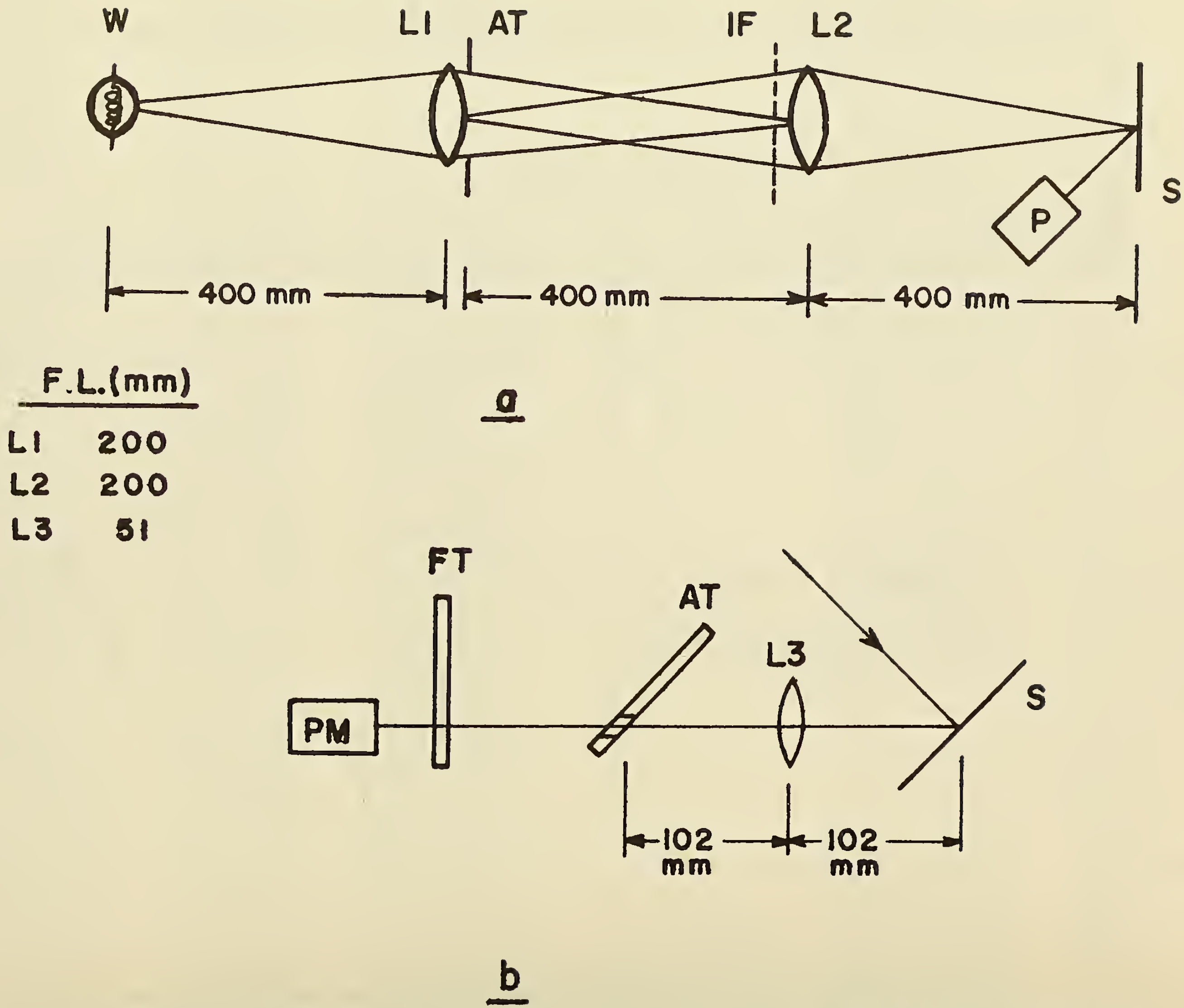


Fig. 6. The setup for measuring the blurring effect with large light beam and small viewed area. 6a. Source -- 6b. Detector
W = tungsten filament source; L1, L2, and L3 = lenses; AT = aperture turrets; IF = interference filter; S = sample; P = photometer; FT = filter turret; PM = photomultiplier

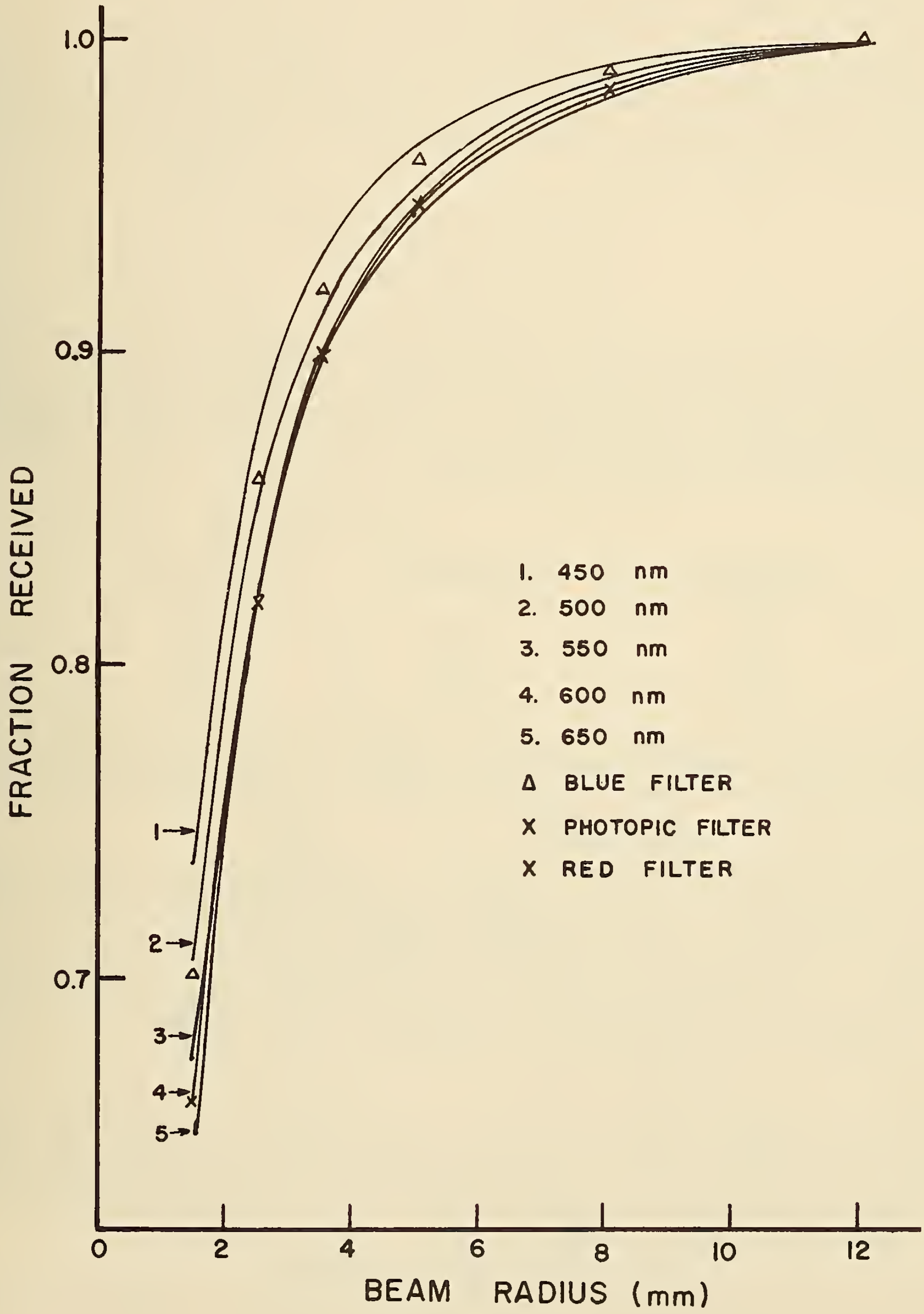


Fig. 7. The fraction received of Vitrolite glass sample as a function of beam radius.

with broadband filters agree with those made with interference filters.

The translucency was further measured with a light spot of 0.5 mm radius on the sample. The small light spot is produced by replacing lens L2 in figure 6a with a lens of 90 mm focal length and placing it 360 mm following the aperture turret. The sample was placed 120 mm beyond the lens. This setup gives a three-to-one reduction. With an aperture of 1.5 mm radius, this arrangement produced a light spot of 0.5 mm radius. The photometer is mounted on an x-y scanner. The light spot on the sample is scanned from the center to a location 15 mm away from the center along one radius. The photometer views an area of 0.1 mm diameter. Measurements are made on the Vitrolite glass sample (11 mm thick) and white paint sample using blue and then red broadband filters. The results are plotted in figure 8. For the white paint sample, measurements made with blue and red filters give the same results. With Vitrolite glass samples, the curves show clearly that at distances away from the light spot, the Vitrolite sample scatters more radiation flux in the red region than in the blue region.

4. PREDICTION AND VERIFICATION

4.1 Error Estimations

The fraction received is predicted analytically utilizing eq. (17) and the function f(r) in eq. (21) for a radiation beam of 3.2-mm radius incident on a Vitrolite sample (11 mm thick) and masks of radii 4.8, 6.4, and 7.9 mm. The fraction received for the above condition is also determined experimentally. The laser beam with a 3.2-mm radius is obtained by adjusting the second lens in the spatial filter. The following table shows the close agreement between experimental and analytical results.

	Fraction Received	
Mask Radius (mm)	Experimental	Analytical
4.8	0.927	0.925
6.4	0.965	0.965
7.9	0.981	0.980

The percent loss is one minus the fraction received and expressed in percentage. Using the equations derived in Part 2 and experimental results obtained in Part 3, we proceed to estimate what would be the fraction received or percent loss with different combinations of beam sizes and sample-port or mask sizes.

With uniform incident-flux distribution and concentric-circular incident beam and sample port (or mask), eqs. (21), (14), and (17) are used to generate curves of fraction received and percent loss. Some data presented in four different ways to bring out different relationships are shown in figures 9 and 10 in linear scales and in figures 11 and 12 in semilog scales. For example, with beam radius of 6 mm and mask radius of 12 mm there is a loss of 0.85% and with beam radius of 12 mm and mask radius of 18 mm there is a loss of 0.39%. Figure 11 indicates the trend with a fixed difference between the mask and beam radii, the smaller the incident beam radius the larger the loss.

In figures 13, the percent flux loss, i.e. $1 - F_x$ expressed in percentage, of the Vitrolite glass (11 mm thick) is shown as a function of the radius of incident ring-shape beam with different mask radius. Light beams are assumed to be of ring shape with various ring radii and all with one-millimeter width. The radii of the mask openings range from 10 to 30 mm. This figure shows that the closer the light beam to the edge of the opening, the larger the contribution to the flux loss.

In order to show how misalignment can cause an increase in flux loss, an example is given below. For an incident beam of 13-mm radius and a sample port of 18-mm radius, the flux loss is 0.39% as mentioned above. If the beam is misaligned by 6 mm, the edge of the beam strikes the edge of the mask. Using the percent losses of ring-shape beams given in figure 13 and eq. (19), the percent losses are calculated as a function of the misalignment up to 6 mm. Results are given in figure 14. The flux loss increases rapidly when the incident beam is approaching the mask.

text continued on page 22

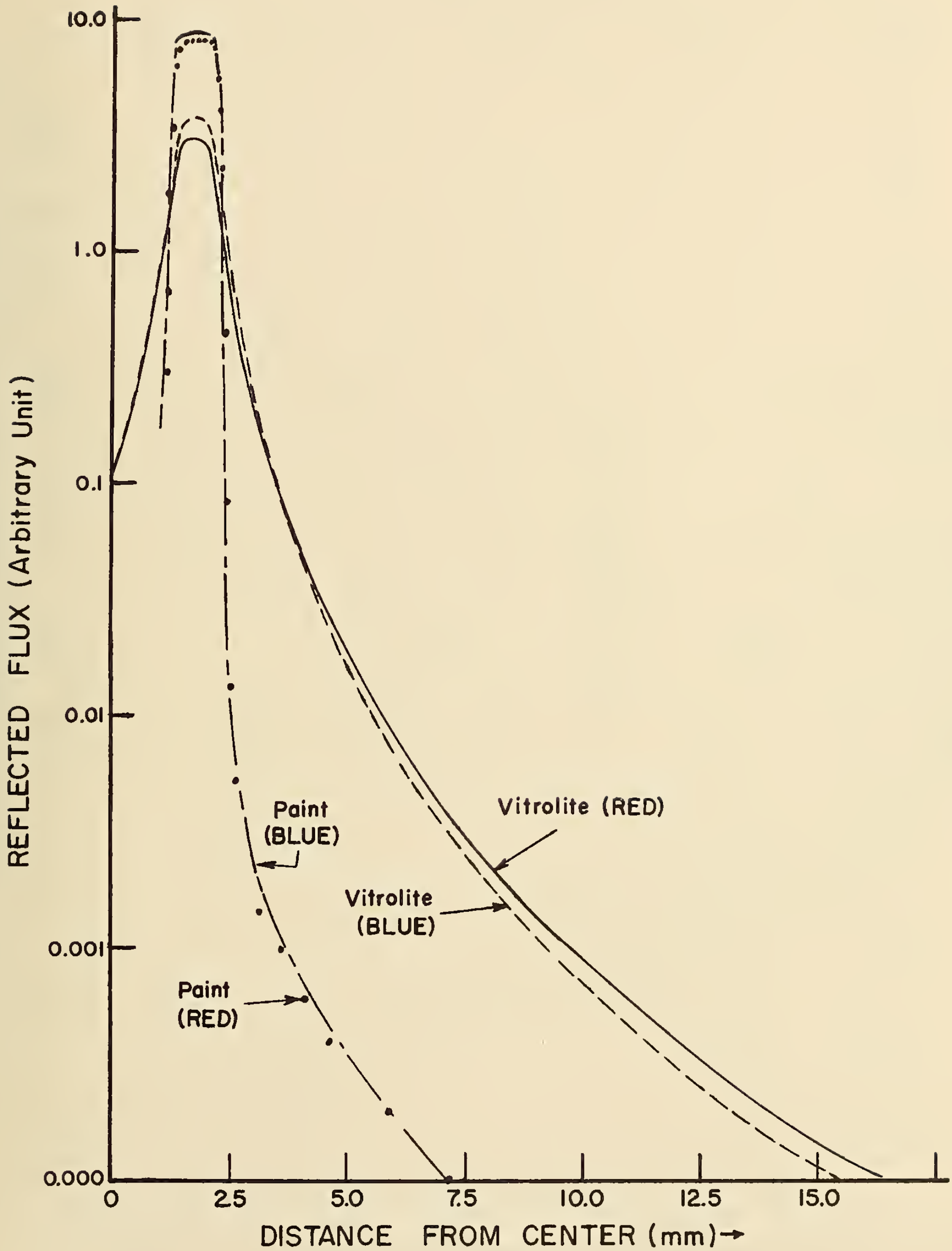


Fig. 8. The reflected fluxes from Vitrolite glass and paint samples as a function of distance from the light spot. (Measurements made with blue and red filters.)

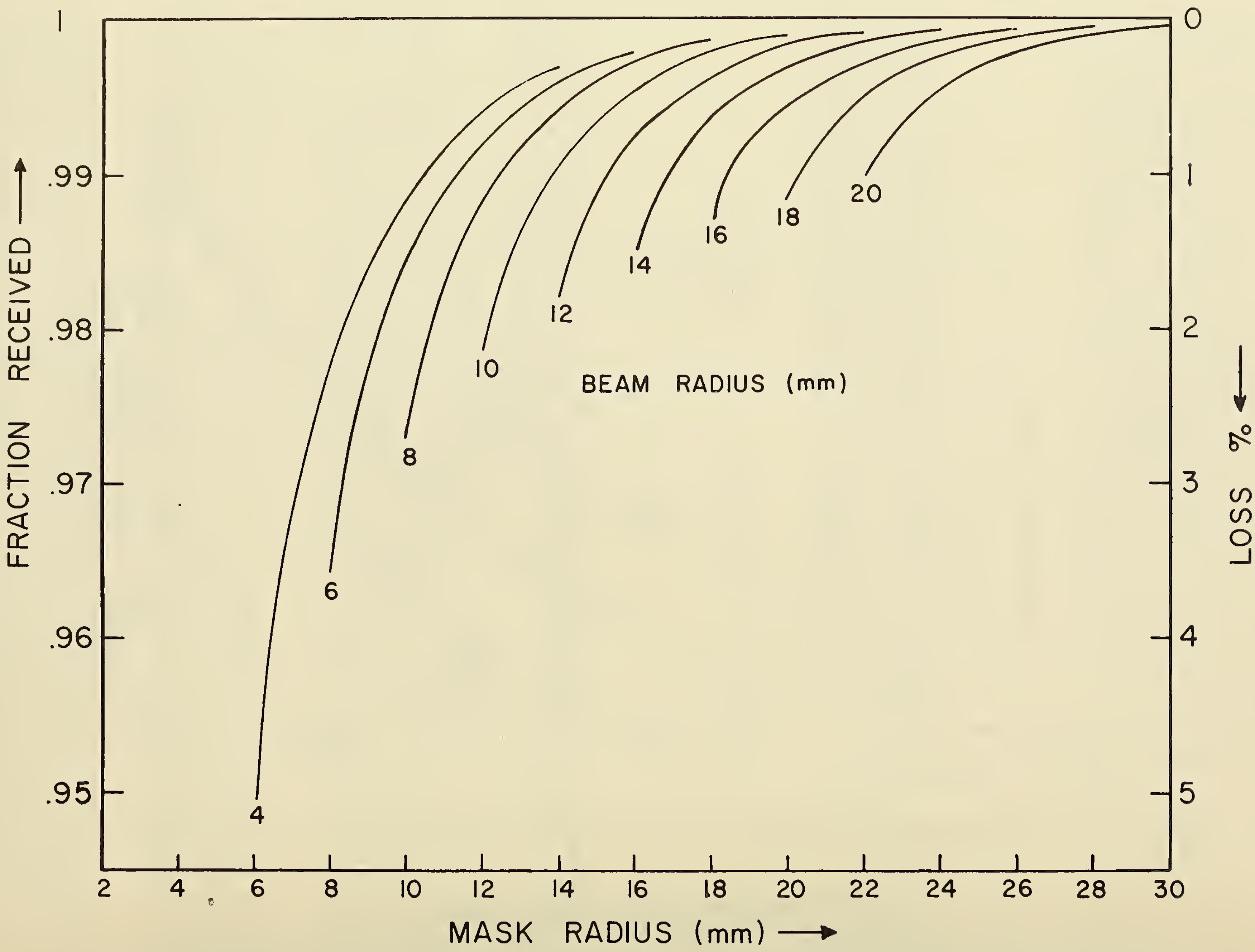


Fig. 9. Percent loss due to the blurring effect - 1.

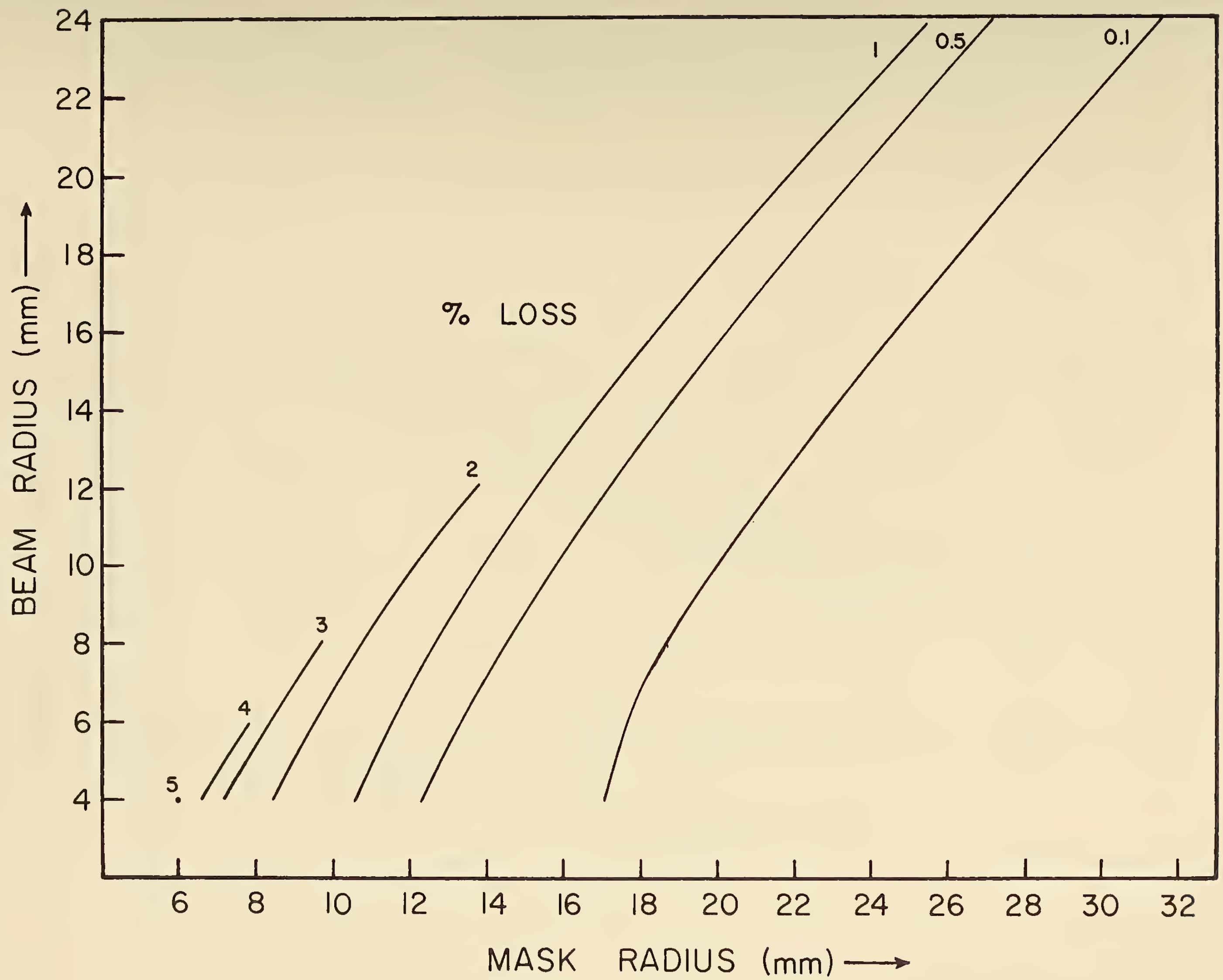


Fig. 10. Percent loss due to the blurring effect - 2.

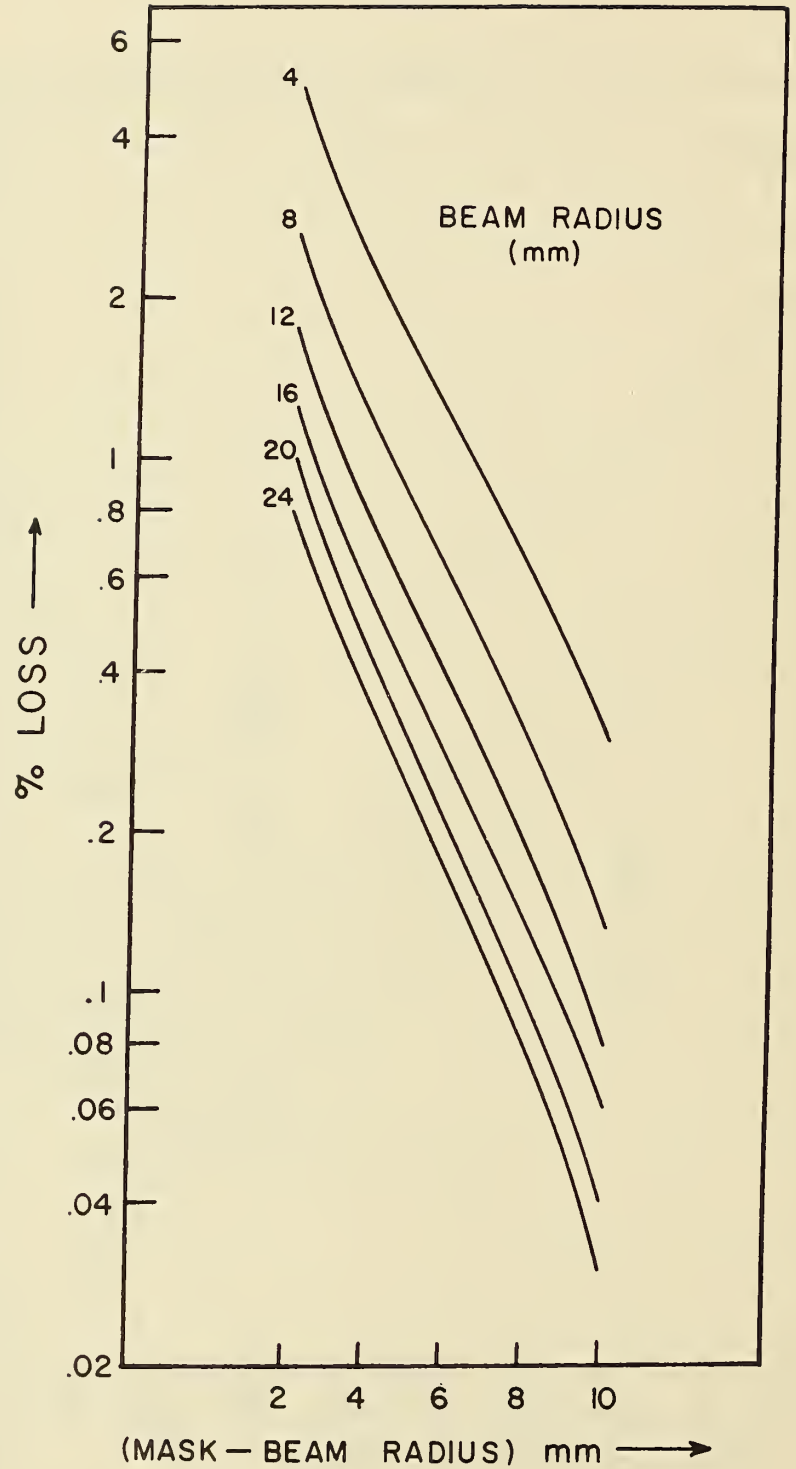


Fig. 11. Percent loss due to the blurring effect - 3.

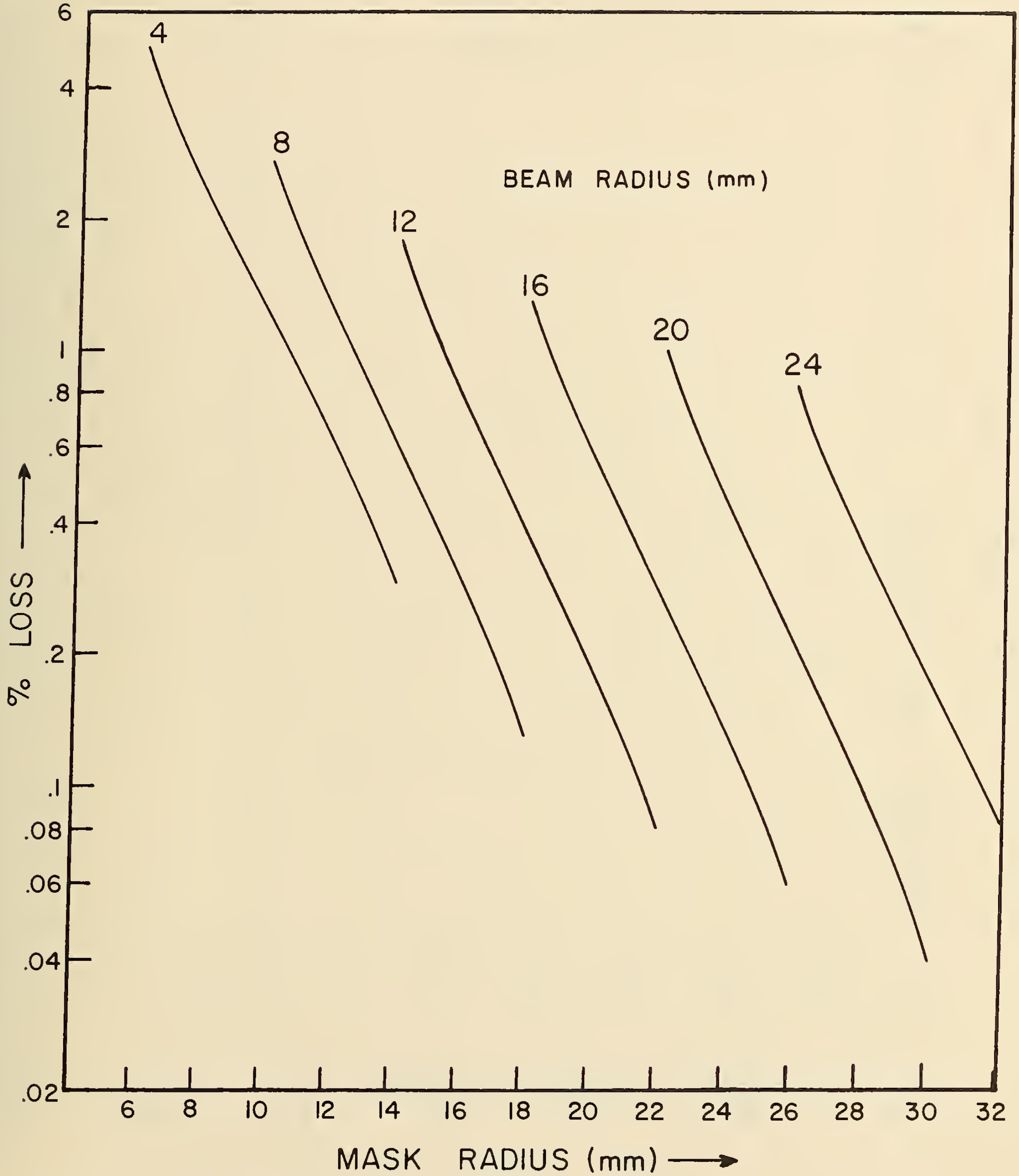


Fig. 12. Percent loss due to the blurring effect - 4.

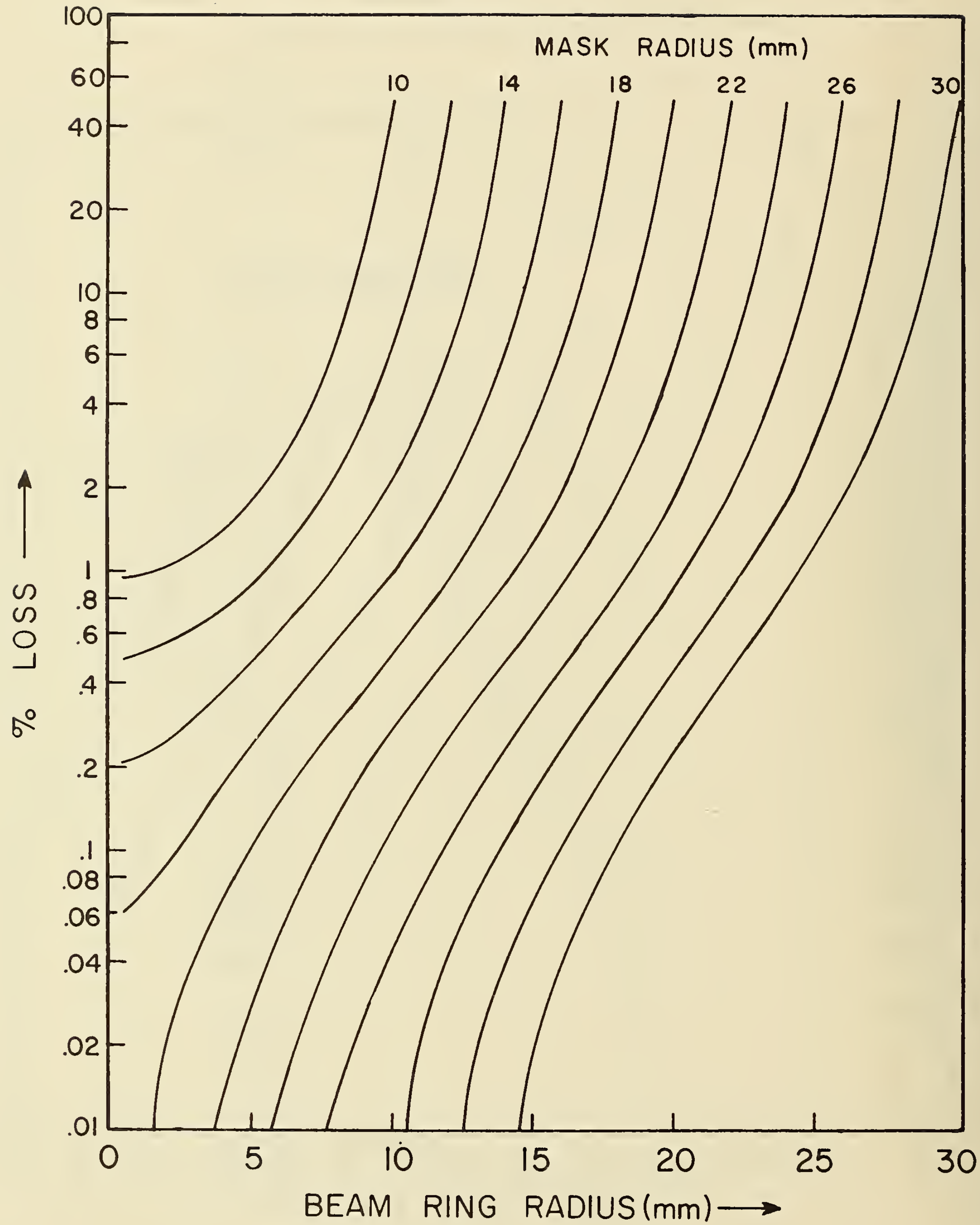


Fig. 13. Percent loss as a function of the radius of the ring shape beam (ring width = 1 mm) with masks of various radius.

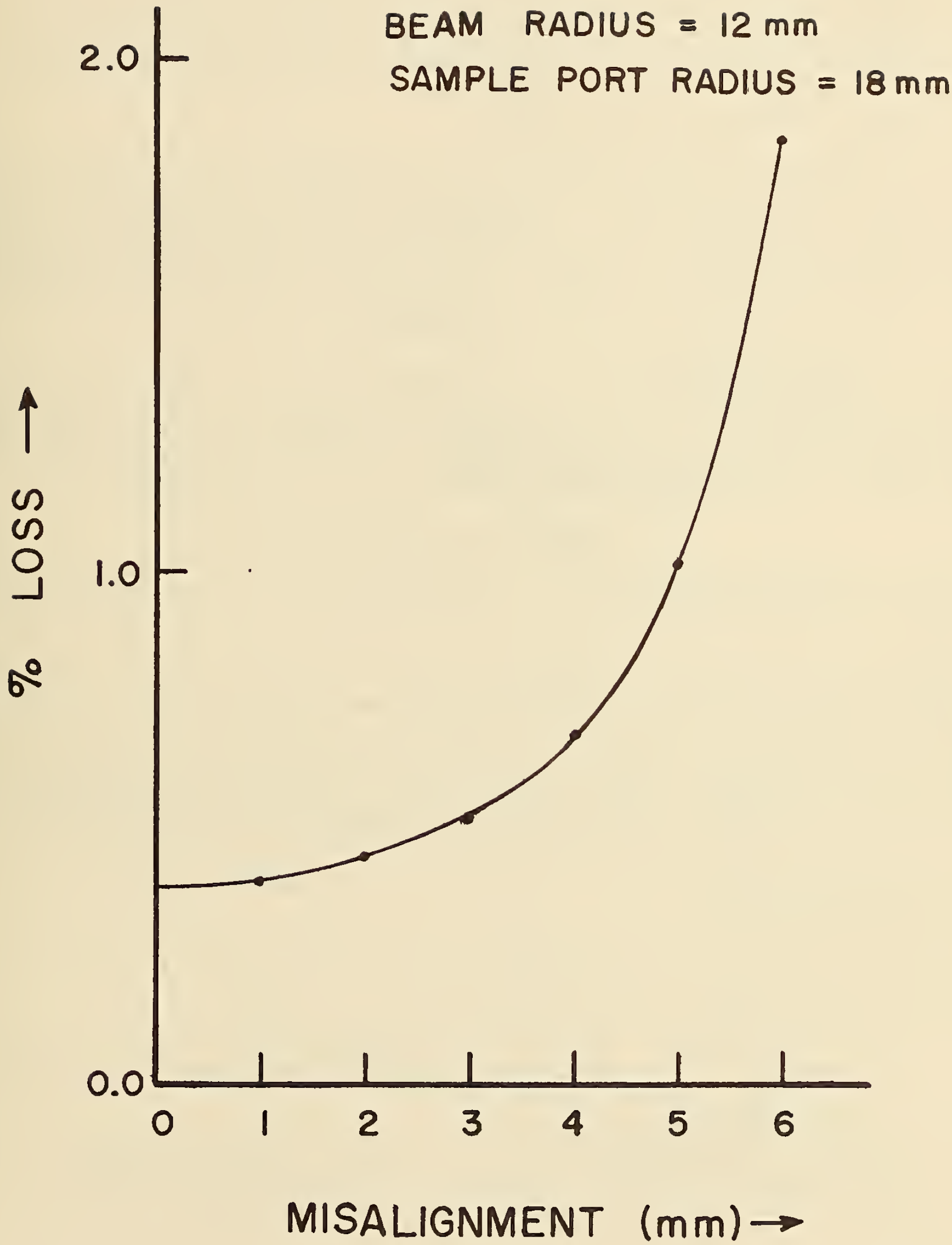


Fig. 14. Percent loss as a function of the misalignment (with the radii of the beam and mask being 12 mm and 18 mm, respectively).

A commercial 45°/0° reflectometer has been evaluated and simulated in order to predict the percent flux loss if a Vitrolite glass is measured.

The detector response R and irradiance $E(\vec{P})$ as a function of location on the sample surface were determined by using a mapping technique. For the measurement of R, the light source of the instrument was blocked and an external source was used to do the mapping. Refer to figure 15. A thin opal glass was placed on an aperture plate which has a 6.4-mm-diameter opening. The ambient light source was irradiated on the opal glass to generate diffuse light. The unit containing the opal glass and the aperture plate was moved on the sample port, so that the aperture opening could be positioned at any location in the sample plane. Nine positions are chosen to do the mapping. Their actual positions and the spatial response of the detector in arbitrary units are shown in figure 15. The results indicate that the spatial response is fairly uniform.

The irradiance distribution, $E(\vec{P})$, on the sample plane, of the light source was mapped by using an external detector. A silicon cell, with 1 mm^2 sensitive area, was positioned by an x-y scanner on the sample port. The normalized irradiance distribution of the incident light beam at the sample port is shown in figure 16 which indicates some scattered light surrounding the main beam. The values of $E(\vec{P})$ from the mapping and f(r) from eq. (21) are used in eq. (8) to perform the numerical integrations. The fraction received calculated is 0.978. Thus the flux loss due to the translucent effect is 2.2%.

A round robin intercomparison of a flat paint sample was conducted by NBS [4]. One of the participating laboratories used an instrument similar to the above mentioned reflectometer and used Vitrolite glass as the standard. The results obtained by that laboratory differed from those obtained at NBS by about 2%, indicating that translucency of the white standard might be the major cause of the error.

5. CONCLUSIONS AND RECOMMANDATIONS

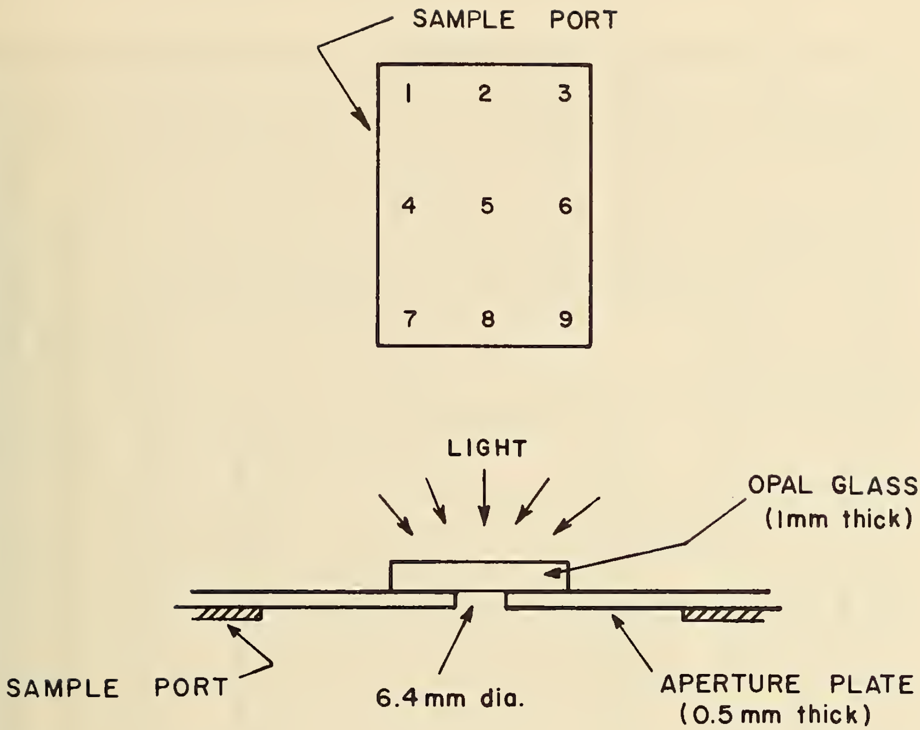
With translucent materials such as plastics and white glasses, the loss due to translucent effect can be a big contribution to the spectrophotometric measurement error.

Methods for mathematically evaluating the flux loss are examined. Equations are derived for several special cases such as uniform irradiance, concentric incident beam and sample port, and misalignment. An experimental setup and methods have been described to show how to evaluate the translucent effect or percent loss quantitatively. Results are given for an 11-mm thick Vitrolite white glass. Several sets of curves of flux loss prediction are presented for a combination of different sizes of the radiation beam and sample port. An actual reflectometer has been simulated and the error due to translucency predicted.

The information presented here can be used to calculate flux loss corrections when a Vitrolite standard is used.

From this study, several recommendations can be made in connection with making spectrophotometric measurements of translucent materials:

(a) Reduce scattered radiation surrounding the main beam;
(b) The size of the sample port should be at least two to three times larger than that of the main beam;
(c) Use large samples;
(d) Align the radiation beam to the center of the sample port;
(e) Be aware of possible error of measurements due to flux loss; and
(f) Correct for translucency or flux loss if possible.



POSITION	FLUX*	POSITION	FLUX*	POSITION	FLUX*
1	3.12	2	3.06	3	2.79
4	3.38	5	3.32	6	3.03
7	3.02	8	3.00	9	2.70

* ARBITRARY UNIT

Fig. 15. Spatial sensitivity of the detector.

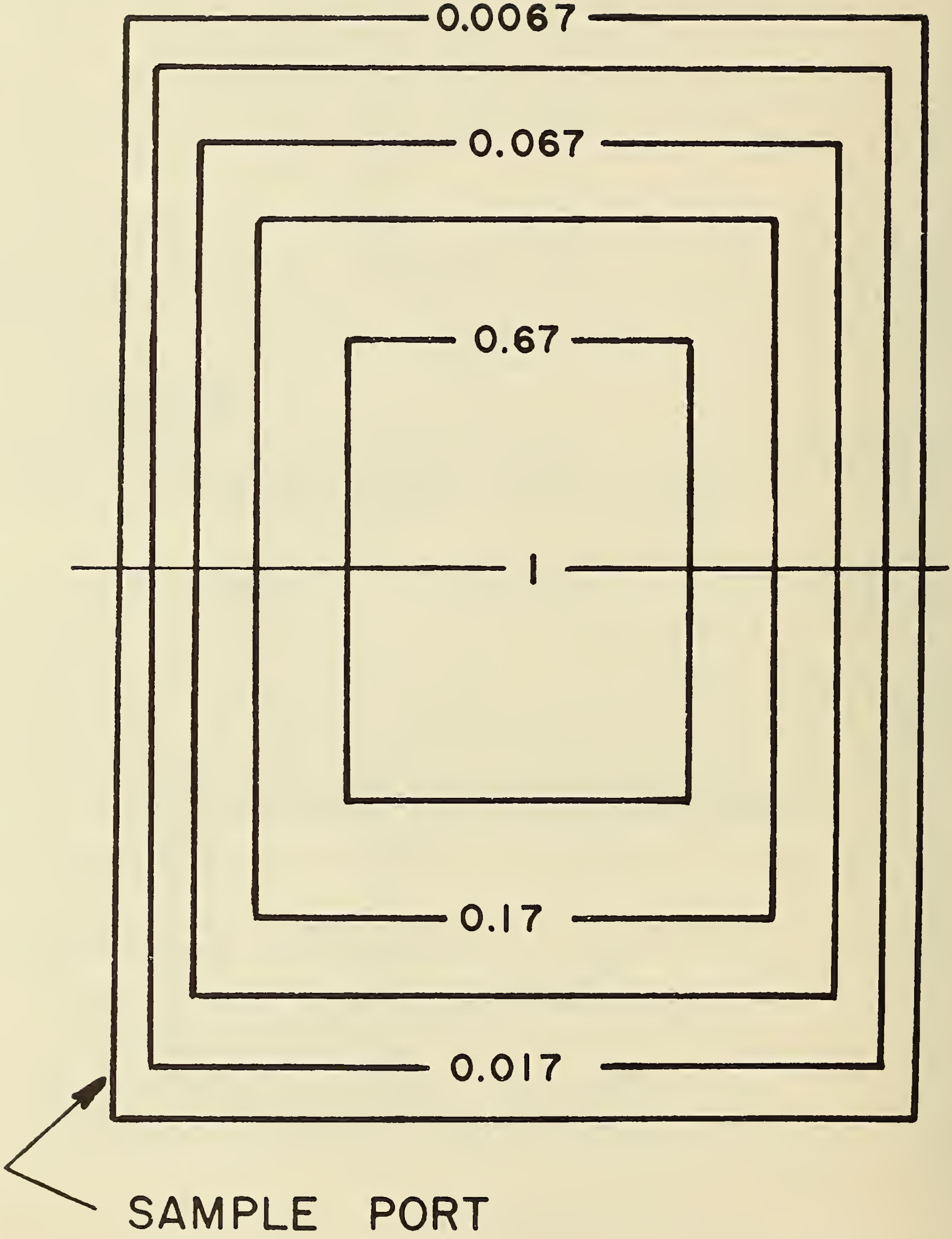


Fig. 16. Normalized flux distribution.

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7. Certain commercial instruments or materials are identified in this Technical Note in order to specify adequately the procedure. In no case does such identification imply endorsement or evaluation by the National Bureau of Standards.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The translucent phenomenon which causes flux loss in the spectrophotometric measurement is described. Methods for mathematically evaluating the flux loss are examined, and experimental methods using laser and conventional light sources are described. A widely used Vitrolite glass standard is employed to demonstrate the error estimation and correction.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Blurring effect; edge loss; error analysis; flux loss; plastics; reflectance; scattering; spectrophotometry; translucency; transmittance; Vitrolite glass.

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