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Electrostatic Imaging in Radiology: Limitations and Prospects

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Electrostatic imaging in radiology: limitations and prospects

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[Plate 1]

In this radiographic technique, the latent image takes the form of a surface distribution of electric charge which may be rendered visible in various ways. The charge distribution is formed either on a selenium surface (xeroradiography) or by collecting ions on an insulating foil (ionography). Conventional powder development techniques yield visible images in which high spatial frequencies are enhanced ('edge contrast') and low frequencies largely suppressed. This contrast pattern is useful for the radiological study of soft tissues, vascular structure, bones and joints. Xeroradiography is less sensitive than film-screen radiography and this restricts its medical application to sites where gonad exposure is minimal. Ionography with compressed xenon has high sensitivity but is not yet fully developed commercially. It requires a rigid link between the X-ray tube and the recording chamber. The latent image is produced on plastic foil which can then be developed in many different ways to yield either edge contrast or density images. Liquid ionography avoids the need for high pressure and allows multiple copies of the latent image to be made. There are some special applications of ionography in the research laboratory but in industrial work xeroradiography, despite lower sensitivity, is likely to be more convenient for any applications which demand edge contrast pictures.

History

The electrostatic method of imaging X-rays was demonstrated in embryonic form within a few months of Röntgen's discovery, by both Thompson (1896) and Righi (1903) independently. The fact that further development of this idea had to wait so long must be attributed partly to their early demonstration having been totally forgotten, but chiefly to the convenience, good resolution and high sensitivity of the silver halide emulsion. The renewed interest today in electrostatic methods is due, at least in part, to the impending threat of a world shortage of silver. There are, however, some technical features of electrostatic imaging which can recommend it in its own right to both medical and industrial users, at least for some special purposes.

The modern period began with the development by Chester Carlson (Carlson 1938; Dessauer *et al.* 1955; Dessauer & Clark 1965) of the selenium plate as a photocopying device. Its application to X-radiography followed soon after (McMaster & Schaffert 1950; Hills *et al.* 1955; Nemet *et al.* 1962) and prototype commercial equipment made by the Haloid Co. was tried out for medical radiology during the 1950s and rejected as insufficiently sensitive and extremely messy. The second generation of commercial xeroradiographic equipment introduced around 1973 by the Xerox Corporation has successfully overcome these objections. Considerable work on xeroradiography has been done in the Soviet Union (Boag 1973; Shneideris *et al.* 1968).

Interest in gas ionization methods of imaging was revived by the ingenious electron avalanche chamber devised by Reiss (1965). This proved to have too low a quantum conversion efficiency and the avalanche amplification introduced excessive 'noise' (Boag *et al.* 1974). The alternative idea of letting a high pressure, high atomic number gas act as both photon absorber and ionized medium arose in several centres about the same time and has since been studied intensively in a number of laboratories and in more than one industrial company (Johns *et al.* 1974; Reiss 1974; Stanton *et al.* 1974; Proudian *et al.* 1974; Peschmann & Grosche 1977; Muntz *et al.* 1977). Xonics Inc. now have commercial mammographic equipment in clinical use.

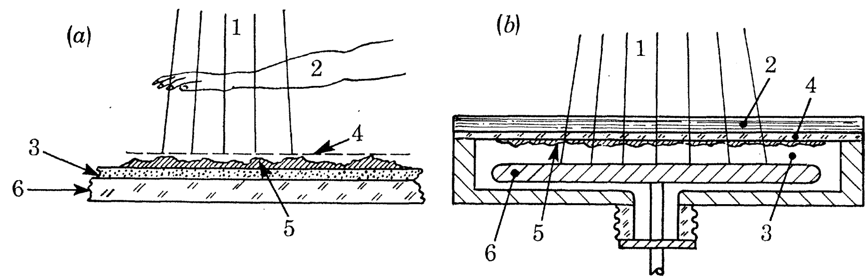

FIGURE 1. Formation of the latent image. (*a*) By xeroradiography: 1, X-ray beam; 2, object; 3, selenium layer 130 μm thick; 4, level of initial priming charge (diagrammatic); 5, residual charge pattern; 6, Al back plate. (*b*) By ionography: 1, X-ray beam emerging from object; 2, carbon fibre top plate; 3, imaging gas; 4, insulating foil; 5, charge pattern due to the accumulated ions; 6, lower electrode at 10–20 kV positive or negative.

PRINCIPLE OF OPERATION

In electrostatic imaging, the latent image takes the form of a distribution of electric charge on an insulating surface. This can be made visible by one or other of a wide range of developing processes. The familiar office copier forms the latent image by focusing visible light onto a thin layer of selenium (or other photoconductor) previously primed with a uniform surface charge. The residual charge left on the surface after illumination is a 'negative' replica of the light pattern, since the leakage current through the Se is proportional to the light intensity at each point. Selenium is rendered conductive by X-rays as well as by visible light, so a latent image of a radiograph can be formed by exposing a charged Se plate, enclosed in a light-tight cassette, to the X-ray beam emerging from the irradiated object (figure 1*a*). The selenium layer has to be thicker to provide adequate absorption of X-rays and it may be backed by elements of higher atomic number to enhance its X-ray response but the principle is identical with that of the visible light copier. In X-ray work there is, however, an alternative way of forming the latent image. One can collect the ions formed by the absorption of the X-rays in a layer of gas or liquid (figure 1*b*). This process is called 'ionography'. If the gas or liquid is confined between metal electrodes across which a high potential is maintained, the ions formed will be propelled towards the oppositely charged electrode, and if one electrode is covered by an insulating foil the charge will accumulate on its surface and form a pattern in which the charge density at each point is directly proportional to the X-ray 'dose' received by the gas immediately above it. The latent image is then a 'positive' (in the photographic sense) of the X-rays entering the gas layer.

Any of the methods of developing electrostatic images that have been devised for the photocopier industry can also be used for making visible the radiographic latent image and it is at this development stage that the tonal pattern of the finished radiograph is determined. The charge image on the insulating surface – whether selenium or plastic foil – contains all of the information about the X-ray intensity pattern in quantitative form. It can be developed to yield a continuous tone picture with a wide grey scale, in which case it will resemble a normal film radiograph. This is achieved, for instance, by the 'magnetic brush' development method or by the use of a liquid 'toner' – that is, a colloidal suspension of charged powder particles. On the other hand, if an aerosol is used, as in the standard 'powder cloud' process in commercial xeroradiography, the high spatial frequencies in the image will be greatly enhanced and the low frequencies largely suppressed to that one sees principally the edges of regions of different density. Between these two extremes it is possible by existing methods to control the development process to give a limited degree of 'edge enhancement' while retaining some continuous tone quality (Thourson 1972).

The limitations of present techniques with respect to sensitivity, resolution, contrast, convenience and economy reside partly in the method of forming the latent image and partly in the choice of development process. It is not possible to consider image formation and development aspects entirely independently, however, since ionography, with the latent image on an inexpensive plastic foil, offers many more possibilities for the development of the image than can be adopted with an expensive selenium plate, which must be handled gently and is reused many hundreds of times.

We shall therefore defer a discussion of the more exotic development techniques to a later section and consider first some of the limitations and prospects for conventional xeroradiography.

Medical applications

In medical work, the particular advantage of xeroradiography is that the edge contrast pattern arising from powder cloud development enhances any small density steps in the latent image and so brings out much more clearly the diagnostic information present in many soft tissue radiographs. It has found a permanent place in mammography (Wolfe 1972) since the borders of any tumour are usually better defined and any fine calcifications present are more strikingly presented by this development pattern. The type of small calcifications present is an important diagnostic criterion for recognizing the early stage of a malignant tumour (figure 2, plate 1). Similarly in venography and arteriography, much fine detail in the vascular pattern can be observed which might otherwise be obscured by the strong shadows of overlying bones or organs (James *et al.* 1973; Kürschner *et al.* 1976). The trabecular pattern in bone and the arrangement of teeth in the mandible are particularly well reproduced (Snyder *et al.* 1977). Stereoscopic views are more vivid and easier to study than with film radiographs (Boag *et al.* 1971). What, then, are the limitations?

The principal limitation in the medical field is that currently available selenium plates and development techniques usually involve a higher radiation exposure for the patient than do film–fluorescent screen methods. The difference is not always large (Boag *et al.* 1976), and in procedures involving no significant gonad dose or those which may be required for the accurate diagnosis of patients showing symptoms of serious disease, there is no reason for rejecting the method, if it is considered to be the most accurate one. However, extension to routine abdominal and thoracic investigations must await more sensitive systems. I discuss below the prospects for obtaining a more sensitive solid state system, but I may remark that in industrial applications, sensitivity will rarely be an important factor, except perhaps when taking pictures with a small radioactive source.

Sensitivity of the selenium plate

Thicker selenium layers (280 μm instead of 135 μm) have already been tested by the Xerox Corporation (Fender 1975) and are said to give about twice the sensitivity, and to require twice the priming charge. There are, however, difficulties in manufacturing the thicker layers without flaws and they are not generally available. Much thicker layers, up to 1 mm, have been described in Soviet publications (Shneideris *et al.* 1968; Varenetskas *et al.* 1974) but, to judge by the illustrations given, they too were by no means fault-free. Existing technology may, therefore, lead in due course to improvement by a small factor, say 2–4, but beyond that one can, at present, only speculate.

The reasons for this are twofold. On the one hand, no satisfactory theoretical model has yet been established for X-ray induced photoconductivity in amorphous selenium and, on the other, little experimental work directed towards elucidating the mechanisms involved has been published. Indeed, even in the meagre data which have appeared there were some striking contradictions. Recently, one discrepancy has been resolved by the discovery (Borasi & Cubeddu 1977) of a numerical error by Donovan (1970) in evaluating the exposure rate. When this is corrected there is rough agreement between the Russian and American workers that the energy absorbed per surface charge neutralized is about 30–50 eV for a field strength of 10^7 V m^{-1} in the selenium. It rises rapidly at lower field strengths, and in the Soviet work (Montrimas & Rakauskas 1972) also increases with the thickness of the selenium layer, suggesting some loss by trapping and recombination.

What seems to be a satisfactory theoretical model has been put forward for the conductivity induced in selenium by *visible light* over a wide range of wavelengths (400–620 nm). This model (Pai & Enck 1975) assumes that the absorption of a photon excites an electron to a high level, from which it and the associated 'hole' may either escape or recombine. The existence of a strong electric field makes escape easier. Using Onsager theory (Onsager 1938) to calculate this escape probability, Pai & Enck (1975) obtained excellent agreement with experiment in the range of high field strengths by assuming Onsager initial radii ranging from 0.84 nm for red light (λ = 620 nm) to 7 nm for blue light (λ = 400 nm). They found it unnecessary to invoke any trapping or recombination of carriers in the bulk of the material for Se thicknesses ranging from 3.4 to 44 μm.

If X-ray induced conductivity is also principally due to field-assisted dissociation of carriers and if recombination in the bulk is not important, as Pai & Enck maintain, then little further improvement in X-ray sensitivity can be expected since the initial priming charge in the

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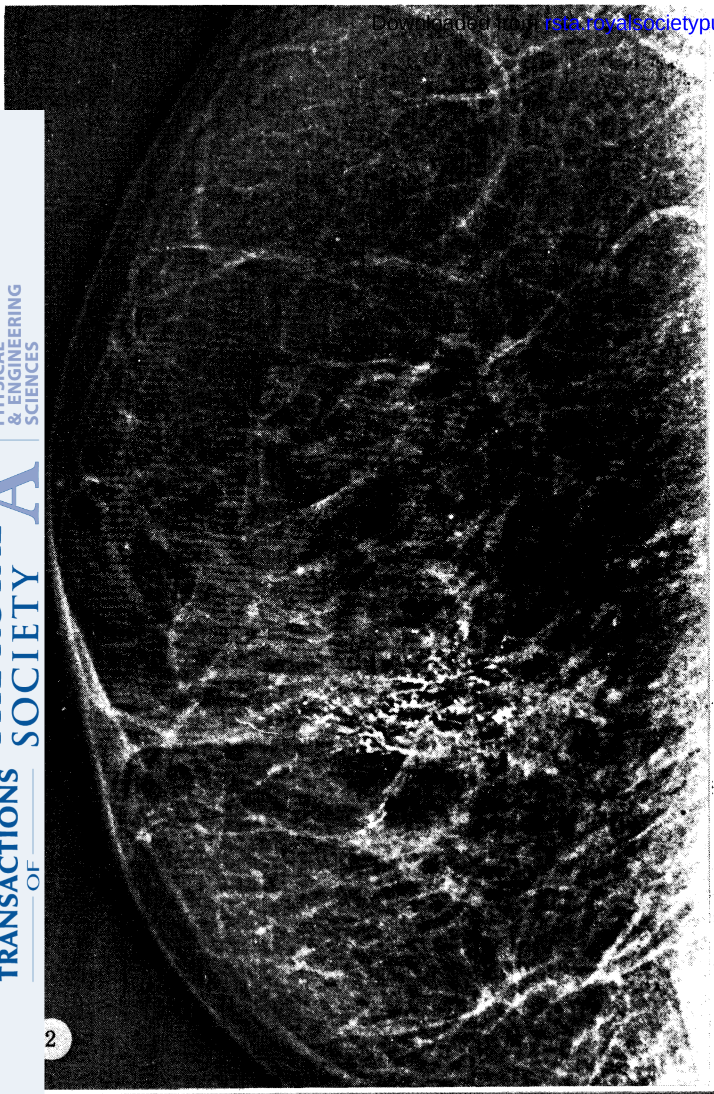
DESCRIPTION OF PLATE 1

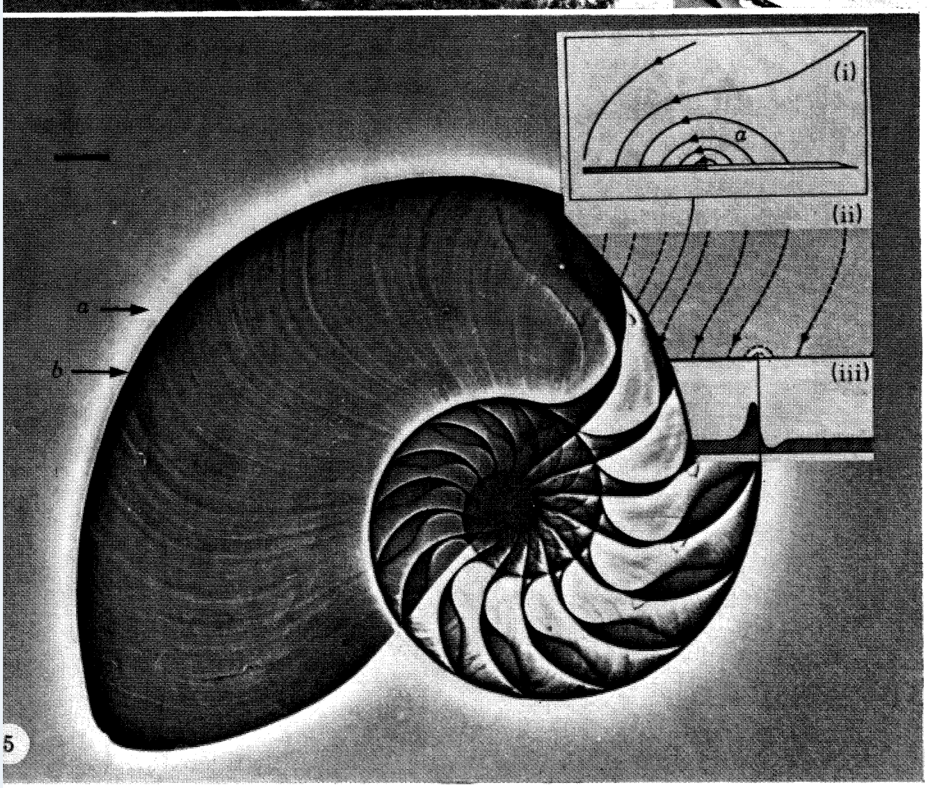
FIGURE 2. Breast xeroradiograph showing well defined fine calcifications which indicate malignancy.

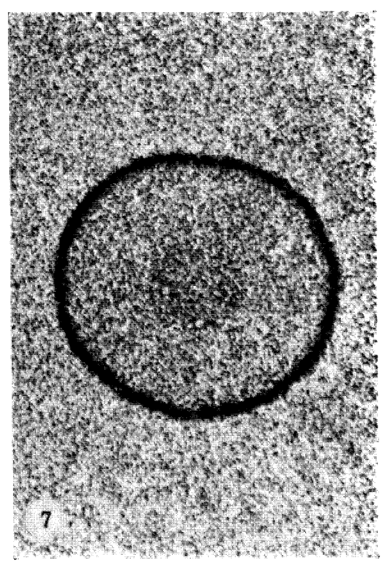
FIGURE 3. Ionograph of foot taken on prototype ionographic chamber (see figure 4) with a 1.5 cm gap and Freon 13-B1 at 5 atm (*ca.* 5×10^5 Pa). (With acknowledgements to the *British Journal of Radiology*.)

FIGURE 5. Xeroradiograph of shell, showing artefacts due to the powder development of a large step in density. These are: (*a*) the 'forbidden region' lying within the closed lines of force (see inset); (*b*) the 'unstable zone' close to the charge step, where the lateral electric force exceeds the friction between powder and foil. The bar represents 1 cm. Inset: (i) lines of force near the step; (ii) powder cloud; (iii) powder coating.

FIGURE 7. Ionographic copy of tritium ring on thin layer chromatography plate (Barish 1976). The ring had a mean diameter of 1.2 cm, a width of 0.5 mm and an activity of 1 μCi cm^{-1}. It was imaged in Freon 13-B1 at 1 atm across a 1 cm gap in 17 h.







Figures 2, 3, 5 and 7. For description see opposite.

existing equipment is about as high as it can be without causing breakdown. If, however, an appreciable amount of general recombination does occur in the thicker selenium layers used for X-ray plates, then further purification might be expected to increase sensitivity by reducing the density of traps. Since charge carriers can be formed and collected by the absorption of visible photons having energies of only 2–3 eV, the present value of some 30–50 eV per charge neutralized for X-ray induced conductivity could perhaps be considerably reduced. The need to maintain a high electric field in the selenium during irradiation to preserve sensitivity is the reason for the high value of priming charge normally used. This, however, brings with it the disadvantage that any small latent image signal superimposed on the priming charge is not easily read out, at least by conventional development processes.

Synthetic materials superior to selenium may ultimately be produced, possibly by incorporating a highly absorbing component into an insulating matrix (Anolick 1965) or, alternatively, pure materials of lower dark resistance than selenium may be pressed into service by automating the complete cycle of charging–exposure–development–copying and making it rapid enough to prevent serious trouble from leakage.

Sensitivity of ionography

It is difficult to make general comparisons between ionography and xeroradiography because so many factors are involved, including in particular the method of development. For some applications, e.g. mammography, satisfactory pictures can be taken by ionography at about one-tenth of the X-ray exposure required by xeroradiography with present techniques. Much of this increase in overall sensitivity must be due to the possibility of developing smaller charge densities in the latent image, when freed from the need for a large priming charge. A direct comparison of the charge deposited or neutralized to form the latent image per unit exposure shows very little advantage for xenon at 10 atm (*ca.* 1 MPa) and 1 cm gap over selenium 135 μm thick when using 30 or 40 kVp radiation (Dance & Boag 1977). The advantage rises with increasing kilovoltage, but above about 100 kVp the electron range in the gas will affect the resolution and the imaging efficiency of gas ionography.

Xenon appears to be the best gas for high energy radiation. Other gases containing atoms of higher atomic number generally have vapour pressure not much above 1 atm (*ca.* 100 kPa) at room temperature and so cannot be used at high pressure. For experimental work the gas Freon 13-B1 (CF_3Br) gives better resolution than xenon though considerably lower sensitivity (figure 3; table 1).

In liquid ionography the problem is not one of absorbing the radiation but of collecting the ions formed. Initial recombination of ions takes a heavy toll even at very high field strength, and there seems to be no way of avoiding this. Tetramethyl tin has been used experimentally by Fenster & Johns (1974) and a few other possible liquids have been examined for suitability by Dance & Boag (1977). The principal advantage of liquid over gas is that it can be used without excess pressure. This permits the use of a thin foil window, with virtually no X-ray absorption, and allows the image to be copied by induction through the window (Fenster & Johns 1976). Moreover, with a heavily absorbing liquid the liquid layer can perhaps be made so thin that the spherical focusing design might be relaxed, thus restoring greater flexibility to the system.

The relative sensitivities of gas and liquid ionography have been calculated by Fenster & Johns (1974) and by Dance & Boag (1977). A synopsis is given in table 1.

The possibility of increasing the sensitivity of gas ionography by employing a limited degree of avalanche amplification has been investigated by Peschmann & Grosche (1977). The loss of resolution demonstrated in their pictures of test objects seems to rule this out, however, and less contrasty pictures would be even more degraded.

Table 1. Relative charge density in the latent image per röntgen incident, referred to selenium as standard

(Condensed from Dance & Boag (1977).)

peak potential kV	Se (135 μm)	CF_3Br (10 atm cm)	Xe (10 atm cm)
30	1	0.8	1.1
40	1	0.8	1.2
70	1	0.9	2.3
90	1	1.0	2.8
120	1	1.0	3.6
150	1	1.0	4.5

Resolution

In medical radiography resolution is nearly always limited by the size of the X-ray target spot rather than by the recording material and in general this limit is seldom higher than 10 line pairs per millimetre and is often lower. Microfocus X-ray tubes cannot be used routinely in medical radiology since the longer exposures that they require would often introduce blurring through patient movement. The figure of 10 line pairs per millimetre can be attained both by the selenium plate and by either high pressure gas or liquid ionography, so it is only for special procedures or in industrial work that the two methods of forming the latent image will be in competition on grounds of resolution. In principle, xeroradiography should be better. The ranges of the photoelectrons, Auger electrons, and fluorescent photons associated with X-ray absorption are some 80 times smaller in the solid photoconductor than in xenon at 10 atm – approximately in the ratio of their electron densities. For this reason even very high energy radiation will give sharp xeroradiographs, and there are advantages for some medical procedures in going to 150 kVp or even 200 kVp for pictures which would have to be taken at less than 100 kVp with film–screen techniques. The surface resistance of selenium is so high that it can preserve detail as fine as 200 line pairs per millimetre (Bickmore *et al.* 1960) for 1 h without appreciable degradation, but it would be impossible to record such fine detail by any ordinary X-ray process.

In ionography, good resolution cannot be achieved unless the electric field which collects the ions is everywhere directed towards the X-ray target spot. The simplest way of satisfying this condition is to make the electrodes spherically curved surfaces, centred on the target (figure 4). The permissible tolerances on accuracy in such a system can be met if the goal is 10 line pairs per millimetre (Seelentag 1976) but only by having a rigid link between the X-ray tube and the ionography chamber. This need be no disadvantage when an X-ray tube is reserved for one special procedure (e.g. mammography) but it will certainly restrict its versatility for general work. Other sources of blurring in ionography are the range of the photoelectrons and Auger electrons, and the lateral diffusion of the ions as they drift through the gas. To restrict the electron range as well as to increase photon absorption efficiency it is usual to

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work at a gas pressure of some 5–10 atm. For reasons which have been set out in detail elsewhere (Johns *et al.* 1974) the peaked charge distribution collected from a single, infinitely narrow pencil of X-radiation has an effective width very much smaller than the average electron range. Thus, experiment confirms that 10 line pairs per millimetre can be resolved when 60 kVp X-rays are absorbed in a 1 cm layer of xenon at 10 atm although the extreme range of the most energetic photoelectrons released under these conditions exceeds 1.5 mm and that of the Auger electrons is 0.4 mm. Under these conditions, also, only 37 % of the ions created by the X-ray pencil are collected within a circle of 0.12 mm radius on the foil (Johns *et al.* 1974), so the range of the secondary electrons does reduce the *efficiency* of high resolution imaging, even though the extreme peakiness of the distribution still preserves fine detail. The K-fluorescent photons, on the other hand, can travel several cms from their point of origin and their reabsorption in the gas merely increases the general background level of ionization, which does not appear as fog if edge contrast development is adopted.

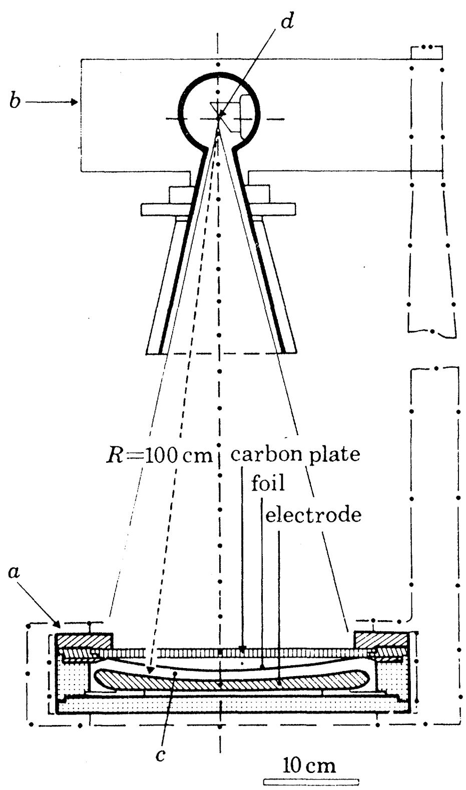

FIGURE 4. An ionographic system comprising an X-ray tube (*b*) rigidly linked to the imaging chamber (*a*) which is 'focused' on the X-ray target spot (*d*); (*c*) is the imaging gas. (With acknowledgements to the *Journal of Photographic Science*.)

DEVELOPMENT PROCEDURES

The development process chosen determines the contrast pattern of the final image and is one factor in the overall sensitivity of the system. If edge contrast is desired, either powder cloud development or 'cascade' development is the simplest choice. In the former process, an aerosol is formed by injecting puffs of toner powder into a large box containing the exposed selenium plate or foil. In the cascade process, on the other hand, the toner particles adhere by electrostatic attraction to much larger 'carrier' granules which are rolled back and forth across the latent image, thus bringing the toner close to the charged surface where the strong image fields 'steal' some of the toner from the carrier (Dessauer & Clark 1965). These processes are applicable to latent images stored either on selenium or on foil.

If the image is on foil there are further possibilities. One of these is 'frost imaging' (Thourson 1972). The foil used for this is composite, having a thin coating of material which softens when heated. This thermoplastic layer 'crinkles' or 'frosts' in the presence of a strong electric field and retains this pattern on cooling. The image is then made visible by scattering of either incident or transmitted light. The spatial frequency of the randomly orientated crinkling is high, about 200 crests per millimetre, so entirely adequate definition is achieved. This process gives a density image, rather than edge contrast. It has not yet been applied to radiographic latent images.

Another possibility of a somewhat similar nature is the 'eidophor' system tried out in the early days of large-scale cine projection (Baumann 1952). In this, a layer of oil or other insulating viscous fluid covers the latent image and is 'modelled' by the electric fields present around steps in the charge distribution. A strong light beam is reflected from the fluid surface onto a screen, so high-intensity illumination is possible. This system yields edge contrast pictures, and an attempt is now being made to exploit it for ionography (Walton 1977).

Artefacts and their control

Powder cloud development has its limitations. It achieves the desired 'edge enhancement' of low-contrast images by attracting the charged powder particles in the aerosol initially to the regions of highest field strength, i.e. to any sharp steps in the charge density of the image. The powder trajectories in the vicinity of such a step have been investigated in detail. They follow the lines of force very closely (Johns *et al.* 1975). It can be seen from figure 5 that there is a region close to the edge into which powder is not drawn. In figure 5 this 'forbidden region' (Lewis & Stark 1972) extends for some 5 mm outside the geometrical edge of the shell, shading off into the background, since eddies in the air will carry some powder particles across the bounding lines of force. There is, however, a more sharply defined white line, only 0.5 mm wide, along the edge. This is a different artefact which has been called the 'unstable zone' (Boag *et al.* 1974) because within this zone, friction cannot hold any fortuitous powder particles against the strong tangential electric force.

The forbidden region can be greatly reduced in width by bringing a 'development electrode' (Dessauer & Clark 1965) close to the selenium surface during development. In general, however, powder cloud development is not suitable for the accurate reproduction of latent images having very large steps in density, in view of the loss of detail in the wide 'forbidden regions'. Very large steps also incur the danger of distorting the latent image itself by 'xerographic undercutting' (Dessauer & Clark 1965). This artefact arises during the X-ray exposure from the erosion of the edge of a charge step by ions of the opposite sign, drawn in from the air above the selenium surface. It is reduced, if not entirely eliminated, by maintaining a strong electric field perpendicular to the plate surface in the air above it during the X-ray exposure.

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The electrostatic latent image as a high-resolution storage device

The ease with which a high resolution radiological latent image can be produced and stored temporarily either on foil or on a selenium surface opens the way to more elaborate methods of readout. Latent images on selenium have been examined in a scanning electron microscope of standard type operated at minimum voltage (5 kV) and at low magnification (Fritz *et al.* 1971). This gave good detail and it is probable that an instrument designed for a much lower voltage would give better results. Alternatively, the stored image could be transferred to an evacuated chamber and the charge density readout by a scanning beam as in the 'plumbicon' television camera, the picture being recorded on video tape and played back at will on an accompanying television monitor. Or, again, the image could be brought into contact with a liquid crystal reader, giving an immediate picture. These are all possibilities for the future, which would require considerable further research and development for their realization.

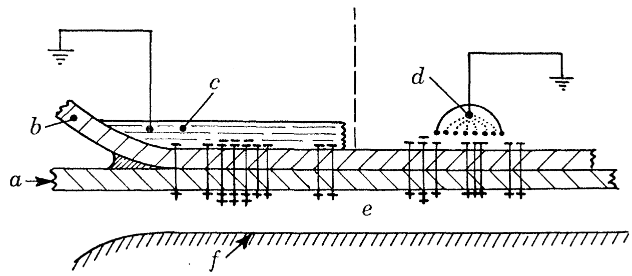

Figure 6. Method of induction copying: (*a*) window foil; (*b*) copy foil; (*c*) conducting liquid, subsequently removed (or (*d*) α-particle source providing ionization for the copy); (*e*) liquid absorber; (*f*) lower electrode.

Multiple copies of the original latent image can be made by induction copying without destroying the original, and these copies can be developed separately in different ways, if desired (Fenster & Johns 1976). The principle of induction copying is illustrated in figure 6. The original latent image must be formed on a thin foil, which is separated from the conducting backing after the X-ray exposure. The second foil, which is to receive the copy, is brought into intimate contact with the back of the original foil, with the use of a few drops of insulating liquid or evacuation of the space to exclude air bubbles. The front surface of the copy foil is then made an equipotential by flowing over it a conducting liquid or an ionized gas. This imprints the image on the copy foil as a charge distribution of polarity opposite to that of the original. The copy can be peeled off and developed without erasing the original charge image, so further copies can be made. The method has been demonstrated in the laboratory on a liquid ionography chamber but it would not seem to be easy to automate it for routine use. Induction copying onto foil has also been carried out with selenium plates but it has not been developed commercially (T. L. Thourson, personal communication).

Unconventional applications of ionography

One can envisage many special applications of ionography. One of these, which has already been described in the literature, is autoionography, the imaging of radionuclide spots present on a thin-layer chromatography plate by their own emitted beta radiation (Barish 1976;

Barish & Boag 1976, 1978). This is a convenient and inexpensive method, quicker than the photographic film and offering much higher resolution than the spark chamber method. It is a particularly simple method for tritium spots, which are not easily imaged on film, and for this, air at 1 atm is an adequate imaging gas. A tritium picture is illustrated in figure 7. Full details are given in the original publications.

Projection radiography should be facilitated by a recording technique which automatically rejects scattered radiation by preserving in the pattern only those ions that are created along lines radiating from the X-ray target spot. Moreover, the high sensitivity of ionography should allow a microfocus X-ray tube to be used without incurring excessively long exposure times.

An analogous application of the spherical 'focusing' principle has been reported (Charpak *et al.* 1974). A spherical drift chamber containing argon at 1 atm was used to image Laue diffraction patterns. Not requiring the highest resolution, they were able to achieve very high sensitivity by using a multiwire avalanche chamber as recording device at the output end of the spherical drift space.

When monochromatic characteristic X-rays are used in laboratory research, one can find combinations of a Kα line and a gas absorber which give high photon absorption efficiency. Only a few millimetres of gas at 1 atm may then give enough absorption. For example, the Ti Kα line at 4.5 keV is 70 % absorbed in only 5 mm thickness of CCl_3F at atmospheric pressure, and spatial resolution should be excellent.

Conclusions

Electrostatic imaging is likely to retain its place as a special-purpose technique in medical radiology and its field of application may grow, especially if the sensitivity of the solid-state system can be increased and if alternative development methods can be brought into routine use.

In industrial radiography, on the other hand, different problems and limitations apply. Where large contrast steps are present in the latent image, edge contrast development shows undesirable artefacts and the best method of readout from a very contrasty latent image may prove to be some form of electronic scanning. The high sensitivity which ionography offers is, again, of little advantage in industrial work, where good resolution is the main consideration. One special application of ionography might be for the production of very large radiographs, since the raw material, plastic foil, is inexpensive compared with film and a simple development process could be chosen. Where high sensitivity is not required, Freon at relatively low pressure could be used instead of xenon. While there appear to be a number of interesting applications of ionography in laboratory work, therefore, in industry it would seem to be still a solution in search of problems.

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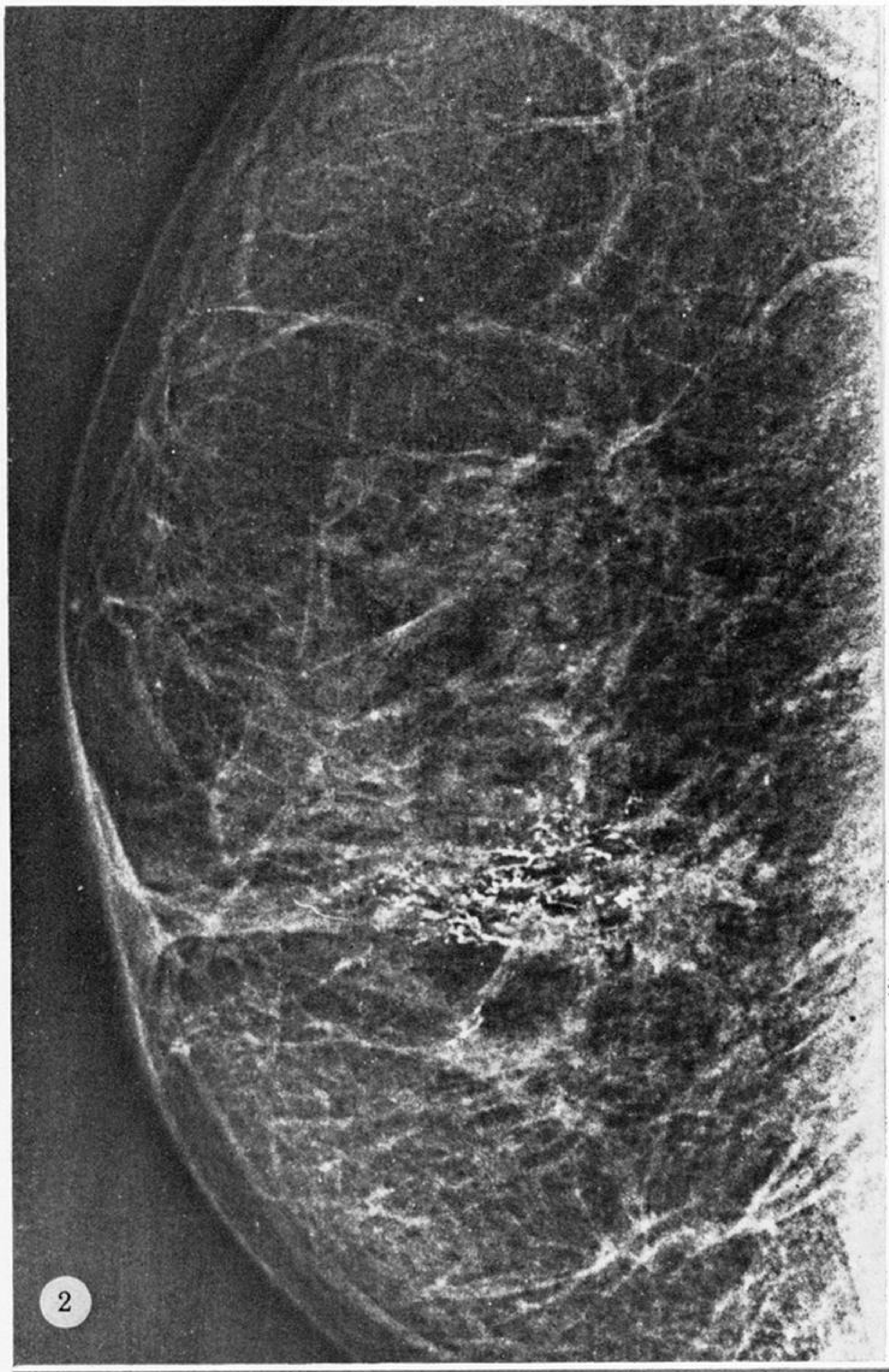

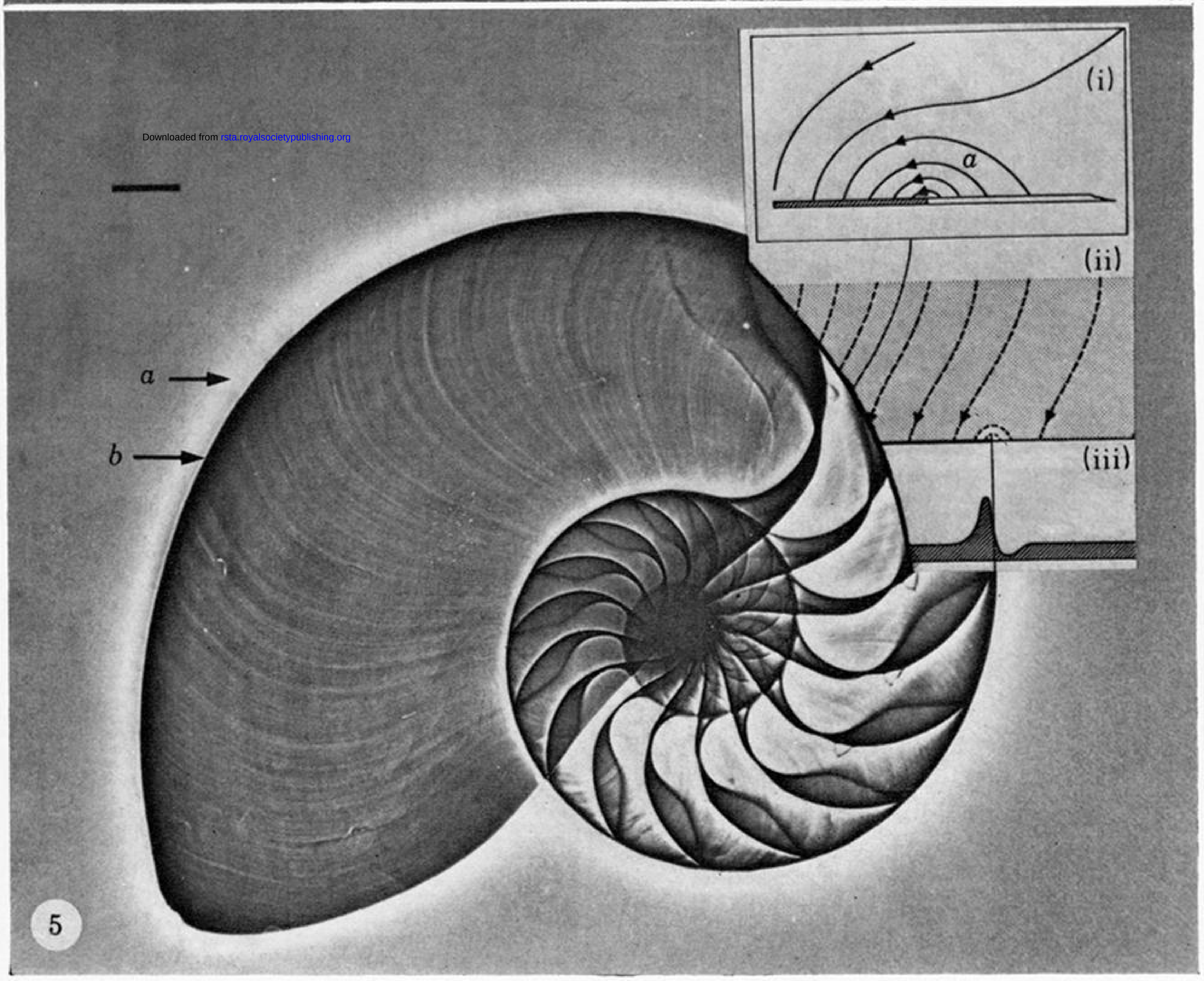

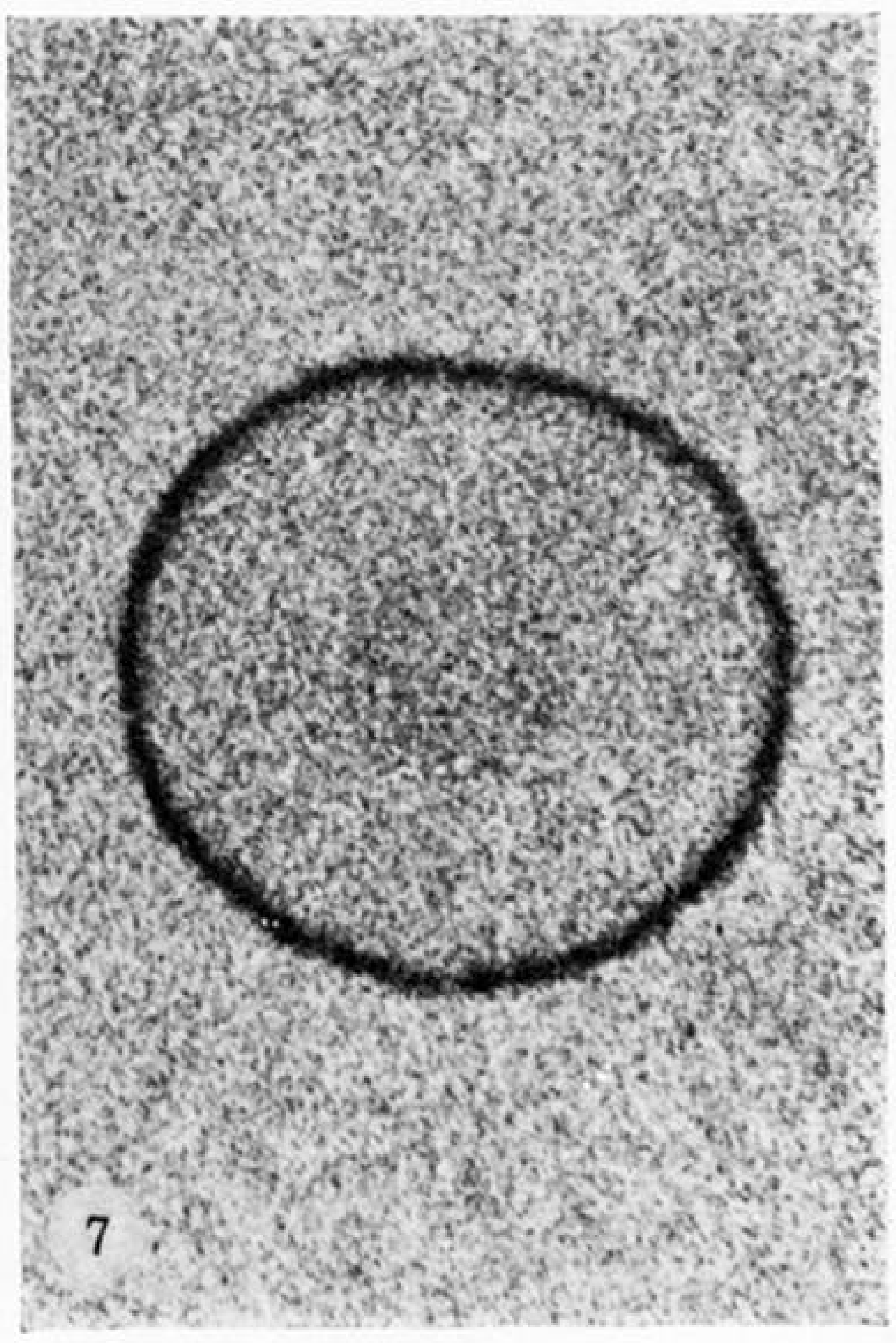

FIGURES 2, 3, 5 AND 7. For description see opposite.