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Fluoroscopes and Fluoroscopy[1]

Carman Lecture

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IT IS CUSTOMARY for the speakers whom you honor with this opportunity to begin their addresses with biographic notes and well deserved praise of the great Russell D. Carman, flavored, if the speaker was so fortunate as to have known Doctor Carman personally, by many an attractive little anecdote, with which the lore of Carman abounds (3, 37).

I, too, knew and loved Russell Carman during his lifetime, as I cherish and revere his memory today. He was more than seventeen years my senior and I well remember the awe with which I first entered his commanding presence. How quickly the geniality and warmth of his personality dispelled my anxiety! His attitude toward us youngsters in the specialty was obviously ideal, and none of us failed to appreciate that he was our friend even before he knew where we were from or what we expected of him.

There is another "Carman Lecture" in these United States, sponsored by the Minnesota Radiological Society and delivered annually at the meeting of the Minnesota State Medical Association. On June 25, 1935, the inimitable Percy Brown used as his title for that Carman Lecture, "The Inception and Development of Fluoroscopy: The Influence of Carman on Its Status in America" (3). The result was a masterpiece, in the best Percy Brown tradition.

The journals of state medical societies are seldom as widely read as they deserve, and *Minnesota Medicine* is no exception. Instead of attempting to add my bit to the large and still growing lexicon of Russell Carman's biography, I am urging your editors and officers to republish, this time in RADIOLOGY, the 1935 address by Percy Brown. Then, if my paper this evening should be deemed worthy of publication, it would make me very happy to have it appear as a sort of technical appendix to Doctor Brown's masterpiece.[2]

For nearly half a century physicists and engineers have devoted themselves to the advancement of roentgenology. Today we have access to apparatus which was undreamed of a few years ago. But these spectacular advances in method and equipment have practically all been in the fields of therapy and roentgenography. Fluoroscopy is much as it was when Carman's first edition appeared in 1917 (8). In fact, there is remarkably little difference between the 1941 models of commercially available fluoroscopes and the one Bob Kelley sold my father back in 1912 (Figs. 1-A and 1-B). And this, in spite of the

[1] Read before the Radiological Society of North America, at the Twenty-seventh Annual Meeting, San Francisco, Dec. 2, 1941.

[2] The Editors have gladly acceded to Doctor Chamberlain's request and with Doctor Brown's permission republish his paper in this issue. See page 414.

fact that changes in equipment for therapy and roentgenography have been so marked that there is little resemblance between the apparatus of today and that of earlier years.

I do not mean that there have been no changes or improvements. In matters affecting convenience and maneuverability, steady progress has been made. Most tilting fluoroscopic tables are now motor-driven; we are today so accustomed to the shock-proof feature that we scarcely recall the days when corona made our fluoroscopic rooms reek of ozone, and we had to warn our patients and assistants to avoid getting too near the high-tension leads; from the standpoint of mechanical design, some really new departures have appeared.

A good example of progress in mechanical design is Dr. John Camp's two-way tilt table, especially designed for lipiodol myelography, but applicable and of advantage in many routine procedures. By an ingenious system of interlocked fulcra (see Fig. 1-C) and an entirely new type of drive, which substitutes cranks and connecting rods for the customary rack and pinion, Doctor Camp's table possesses a full 180 degrees of tilt motion, so that it will stand erect upon either end.[3]

In 1924, Schittenhelm and Wels described a special "multiplane" fluoroscope for use with artificial pneumoperitoneum (see Fig. 1-D). This ingenious device surely deserves more attention than it has thus far received. Now that we have facilities for rendering it shock-proof, its extreme flexibility could be put to excellent use. For example, the cardiac end of the stomach and the occasional "hidden pylorus" might be expected to reveal themselves with greater reliability in the unusual positions and directions of projection of the fluoroscopic beam made possible by this device.

When I arrived at Temple University Hospital eleven years ago, Dr. Chevalier Jackson had just organized and equipped the fine new Bronchoscopic Clinic in which he was to spend the last of his many illustrious years of active practice. Naturally, when Doctor Jackson threw in his lot with Temple, the University did not stint in equipping his new department, and the biplane fluoroscope which was installed there was the best that was procurable at that time. Soon after my arrival, I found myself in the fluoroscopic room with Doctor Jackson, a number of his assistants, and a little patient with a pin in her lung. A half hour later the pin had been recovered, through the bronchoscope, but I came away from that experience with a determination to do something to improve the fluoroscopic features of Doctor Jackson's work. It was obvious that the help he was getting from the fluoroscopist was inadequate and that many of the shortcomings of the equipment were remediable. I sat down and made a memorandum of the more obvious ways in which the apparatus and the method were at fault.

The intensity of illumination, particularly in the lateral beam, was inadequate, and the fact that oil-immersed units were used to make the equipment shock-proof imposed definite limitations upon the intensity of beam that could be employed. On account of these limitations of output, inherent in the oil-immersed units, in which the voltage factor was particularly limited, the apparatus was necessarily operated quite close to the patient. This resulted in a high intensity at the patient's skin in spite of a low intensity at the screen. My r-meter disclosed the fact that operation of the lateral beam for as little as twenty minutes would bring us to the limit of

[3] The usual arrangement for tilting a fluoroscope on a fixed axis or bearing commonly introduces a problem of clearances. Sometimes the design is such as to prevent the employment of target-skin (table top) distances greater than 15 or 16 inches. Later in this paper the advisability of much greater distances will be emphasized. Before such "telefluoroscopic" features can be built into the conventional types of tilt-table fluoroscopes that are on the market today, it is usually necessary to (*a*) introduce an undesirable increase in the height of the table top above the floor, and (*b*) do away with the portion of the tilt that lowers the patient's head ("Trendelenburg"). A study of Doctor Camp's table has suggested to the author that it would be possible to take advantage of the absence of the usual fixed axis or bearing, to obtain up to 30 inches of target-table top distance, without the necessity of raising the table above the usual 34 to 34.5 inches, and without discarding the Trendelenburg feature.

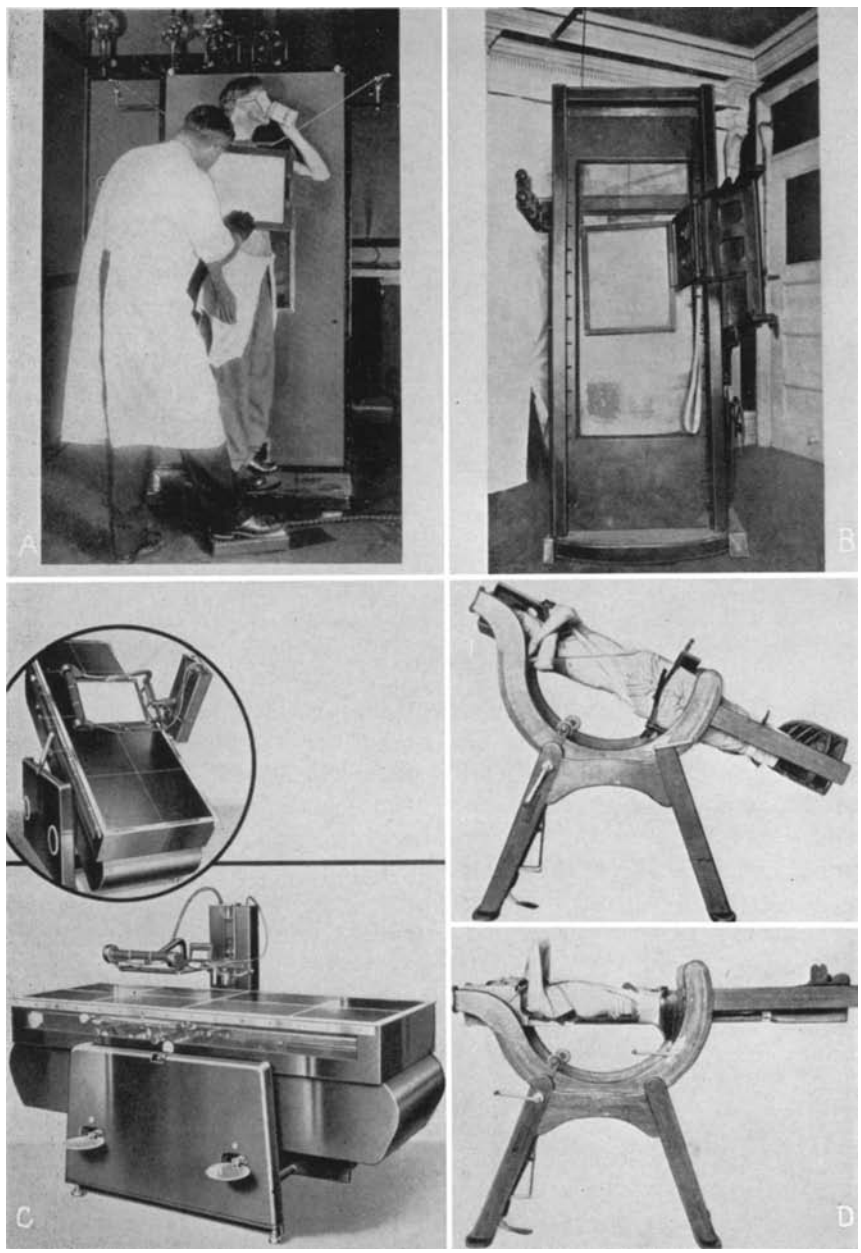

Fig. 1 A. An old "vertical" fluoroscope, pictured on page 40 of the 1917 edition of Carman and Miller: "The Roentgen Diagnosis of Diseases of the Alimentary Canal." Note the similarity to existing types. Such improvements as have occurred have been purely mechanical and in no sense fundamental.

B. An early fluoroscope of the "tilting" type, designed by Doctor Eugene Caldwell. (Photograph from Am. J. Roentgenol. **5:** 561, 1918.)

C. Dr. John D. Camp's two-way tilt table, especially designed for lipiodol myelography but of interest here because its novel system of connecting rods and fulcra, replacing the usual axle and gear-segment, could open the way to a desirable increase in target-screen and target-skin distances.

D. The device of Schittenhelm and Wels for mechanically increasing the flexibility of fluoroscopy in connection with pneumoperitoneum. With modern cable-connected shock-proof tubes it offers possibilities of improving the reliability of roentgen diagnosis in the gastro-intestinal tract. (Photograph from "Lehrbuch der Röntgendiagnostik," Springer, Berlin, 1924, p 986.)

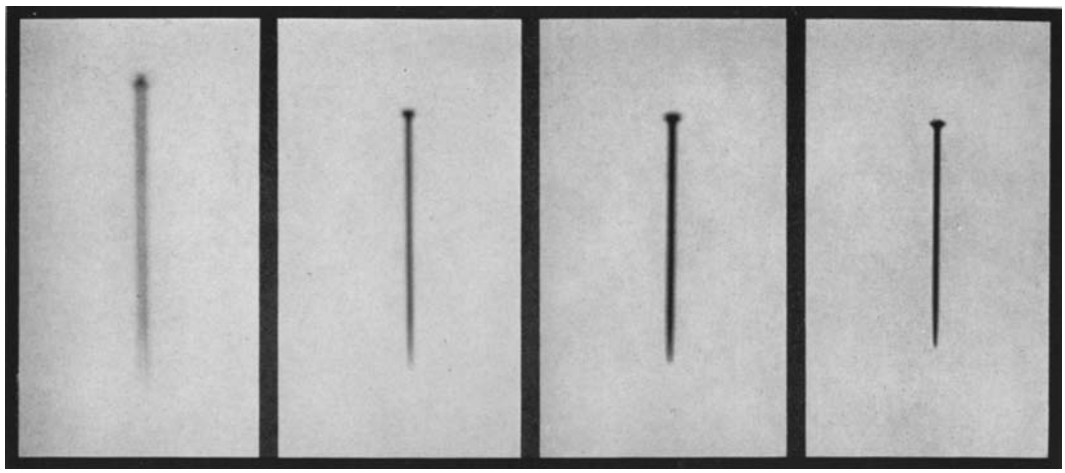

Fig. 2. Entirely aside from its salutary effect upon x-ray exposure of the patient's skin (see Fig. 4 and Table I), increase of the target-screen (and target-skin) distance produces marked improvement in sharpness. In each of the four fluoroscopic procedures pictured here, the foreign body, an ordinary straight pin, was 6 inches from the screen. The target-screen distances were, respectively, 16, 25, 30 and 48 inches. The tube was a "round-focus," "radiator" type such as was frequently used ten years ago in oil-immersed, shock-proof fluoroscopes for biplane guidance of the bronchoscopist. With the shorter distances the observed shadow was sometimes entirely penumbral.

safety. A further untoward result of the necessarily short target-skin distance was crowding of the all-important "head holder," the assistant to the bronchoscopist upon whom devolves the responsibility of maintaining the patient's head and neck in the proper position for the bronchoscopic procedure. From my first experience I could see that the carefully studied technic for which Doctor Jackson is famous was being dangerously disrupted by manipulation of the biplane fluoroscope. The huge oil tanks in which were mounted the x-ray tubes and transformers were banging into the shins of the bronchoscopist and displacing the "head holder" to a degree which made his work almost impossible.

Another untoward result of the unfortunate closeness of the x-ray tube focal spot to the patient was the blurring of the shadow of the foreign body. The distance of the pin from the screen was great enough and the focal spot of the x-ray tube broad enough so that the shadow of the foreign body was almost entirely penumbral. As a matter of fact, I am not sure that any of the umbra reached the screen (see Fig. 2).

I was fortunate in having as my engineer Mr. O. C. Hollstein, an exceptionally fine mechanic who had worked with Dessauer and other well known radiologists before coming to America from Germany in 1929. Stimulated by a close proximity to Chevalier Jackson and inspired by his unselfish devotion to the welfare of his patients, we began to build fluoroscopes with various novel features. The model which has stood the test of time is shown in Fig. 3, but we arrived at our goal a little at a time and I think we would have to assign the number 5 or 6 to this particular apparatus, which has remained continuously in service for the past six or seven years.

The special features of this apparatus are, briefly, as follows:

1. Adequate target-screen (and target-skin) distances, the normal operating positions of the screen being, respectively, 48 inches from the horizontal beam focal spot and 54 inches from the vertical beam focal spot. The corresponding focal-skin distances are, respectively, 36 and 44 inches.

2. Relatively high energies in both x-ray beams, made possible through the use of water-cooled tubes at voltages up to 110 kv.p. and currents up to 18 ma. for short exposures, and up to 6 ma. for continuous or nearly continuous operation.

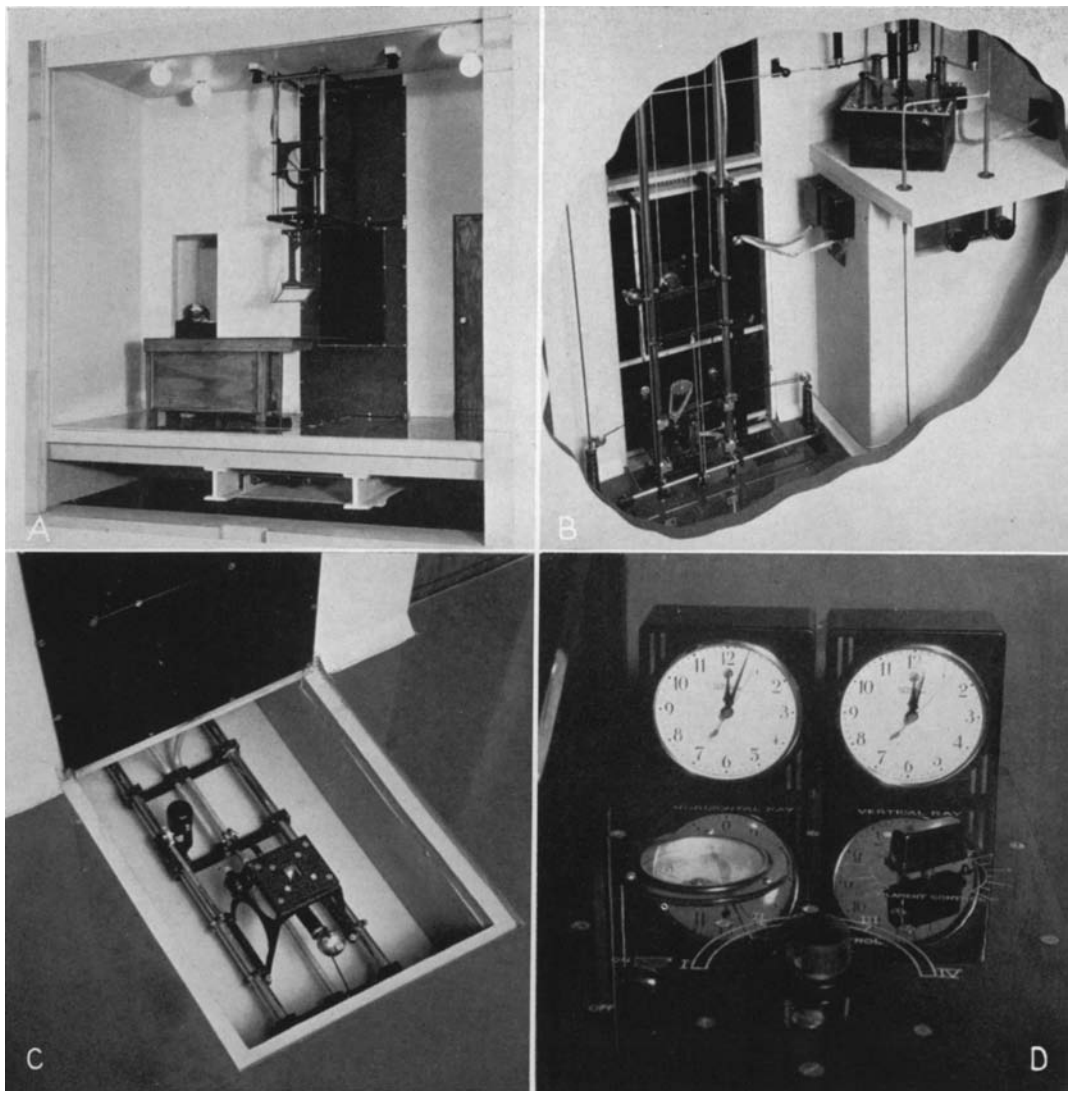

Fig. 3. Home-made biplane fluoroscope at Temple University Hospital.

A. Photograph of an accurately proportioned model, permitting visualization of much detail which is hidden in the case of the device itself. X-ray tube for vertical ray is situated below bakelite panel in steel floor plate, resulting in approximately 54 inches target-screen distance. X-ray tube for lateral beam is situated behind bakelite panel in wall. Toggle switches and push buttons, on screen support within easy reach of radiologist, control electrically driven fluoroscopic shutters, high tension switch for selection of beam, and booster for momentarily increasing brightness of screen.

B. Photograph of high tension compartment behind wall panel to show steel tubing framework, horizontal beam x-ray tube, remote controlled motor-driven high-tension switch and x-ray transformer on shelf.

C. Photograph of vertical beam x-ray tube and its mounting after removal of steel floor plate. The electric motor which drives the cross-travel of the vertical beam tube is seen at the left. Remote control for this is situated on the member which supports the fluoroscopic screen.

D. Self-starting electric clocks are connected so that they record, respectively, the times of operation of the vertical beam and horizontal beam x-ray tubes. This is accomplished through low-tension switch operating in concert with high-tension selector switch. At the beginning of each procedure the clocks are set at 12. Such electric clocks of the self-starting type are available everywhere at prices below $5.

3. A system of remote controls, through finger-tip push buttons and toggle switches, with which the operator chooses the desired shutter openings, which of the two x-ray beams is desired, and which of two available power settings is needed at any particular moment.

4. Rigid correlation of screen move-

TABLE I: RATIO BETWEEN r PER MINUTE AT PATIENT'S SKIN AND r PER MINUTE AT THE FLUOROSCOPIC SCREEN, FOR VARIOUS FLUOROSCOPIC TECHNICS

Type of Fluoroscope; A or B*	Kv.p.	Ma.	Cm. Thickness of Pressdwood Phantom	Inches Equivalent Thickness of Human Body	Distance: Focal Spot to "Skin" (Surface of Phantom) (Table Top)	Distance: Focal Spot to Screen	Distance: Table Top to Screen	r/Min. at "Skin" (R_0)	r/Min. at Screen (R_1)	Size of Illuminated Area at Screen	Ratio R_0/R_1
B	60	8	20 cm.	Abdomen 7 in.	13 in.	24 in.	11 in.	56.4	0.0225	5 cm. × 5 cm.	2,500
B	60	8	20 cm.	7 inch abd.	26 in.	37 in.	11 in.	17.8	0.0118	5 cm. × 5 cm.	1,510
B	60	8	20 cm.	7 inch abd.	37 in.	48 in.	11 in.	8.8	0.0066	5 cm. × 5 cm.	1,340
B	80	4	20 cm.	7 inch abd.	13 in.	24 in.	11 in.	46.0	0.033	5 cm. × 5 cm.	1,390
B	80	8	20 cm.	7 inch abd.	26 in.	37 in.	11 in.	25.8	0.0307	5 cm. × 5 cm.	840
B	80	8	20 cm.	7 inch abd.	37 in.	48 in.	11 in.	12.85	0.0174	5 cm. × 5 cm.	740
B	100	4	20 cm.	7 inch abd.	13 in.	24 in.	11 in.	68.2	0.0758	5 cm. × 5 cm.	900
B	100	8	20 cm.	7 inch abd.	26 in.	37 in.	11 in.	38.3	0.0696	5 cm. × 5 cm.	550
B	100	8	20 cm.	7 inch abd.	26 in.	37 in.	11 in.	43.1	0.1612	20 cm. × 20 cm.	270
B	100	8	20 cm.	7 inch abd.	37 in.	48 in.	11 in.	18.9	0.039	5 cm. × 5 cm.	485
B	60	8	10 cm.	8 in. thick thorax	26 in.	37 in.	11 in.	17.8	0.118	5 cm. × 5 cm.	150
B	80	8	10 cm.	8 in. thick thorax	26 in.	37 in.	11 in.	25.8	0.316	5 cm. × 5 cm.	82
B	100	8	10 cm.	8 in. thick thorax	26 in.	37 in.	11 in.	38.3	0.651	5 cm. × 5 cm.	59
A	79	4	10 cm.	8 in. thick thorax	11 in.	23 in.	12 in.	30.0	0.1924	15 cm. × 15 cm.	156
A	79	4	15 cm.	5 in. thigh	11 in.	23 in.	12 in.	30.0	0.0713	15 cm. × 15 cm.	421
A	79	4	20 cm.	7 inch abd.	11 in.	23 in.	12 in.	30.0	0.027	15 cm. × 15 cm.	1,110
A	79	4	25 cm.	8 1/2 inch abd.	11 in.	23 in.	12 in.	30.0	0.0127	15 cm. × 15 cm.	2,360
A	79	4	27 cm.	9 1/4 inch abd.	11 in.	23 in.	12 in.	30.0	0.0099	15 cm. × 15 cm.	3,030

* Type A is a commercially available fluoroscope of conventional design with "oil-immersed" unit (x-ray tube and transformer in same oil tank), for "self-rectified" operation. Type B is a home-made device using cable-connected, oil-insulated, oil-cooled x-ray tube and 4-valve, full-wave-rectified transformer (see Figs. 4-B and 7-B). At 4 to 8 milliamperes the wave form approaches "constant potential" because of condenser effect of the unusually long (40 feet) shock-proof cables.

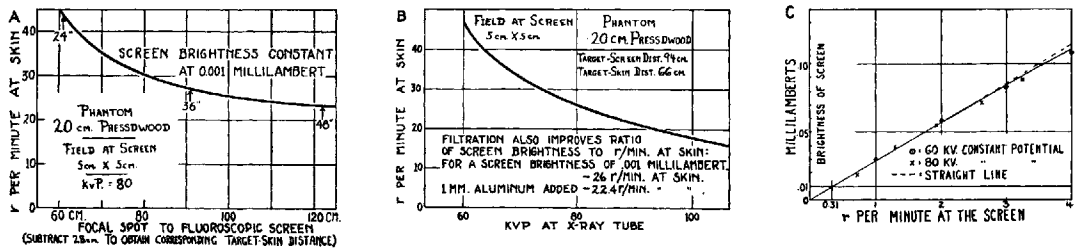

Fig. 4 A. Reference to Table I will indicate the purpose of these graphs. Note that target-skin distances were 13, 25 and 37 inches when target-screen distances were 24, 36 and 48 inches, respectively. Careful comparison of human abdomens with pressdwood phantoms indicates that 20 cm. of pressdwood is equivalent to an abdomen 17.5 cm. (7 inches) thick.

B. Elevation of the voltage is an extremely efficient method of reducing the intensity at the patient's skin for a given fluoroscopic screen brightness. If the "inherent filter" (window of x-ray tube plus table top, etc.) is not unusually thin, added filtration produces only moderate decrease in intensity at the skin. The effect of added filtration, recorded here, was obtained at 80 kv.p.

C. From this graph it becomes apparent at once that response of the Type B Patterson screen is approximately linear with respect to r per minute reaching the screen. Like intensifying screens used with x-ray film, fluoroscopic screens have a temperature coefficient (brightness is increased with reduction of the temperature), but within the ordinary range of room temperatures that obtain in clinical fluoroscopy this is entirely unimportant.

ments with x-ray tube and fluoroscopic shutter movements so that the x-ray beam will always fall upon the protective lead glass shield after it has traversed the fluorescent screen.

5. No interference with the work of the bronchoscopist or his assistants, since, with the exception of the screen and its support, the apparatus is either beneath the floor panel or behind the side wall, which is an ample distance from the bronchoscopic table.

More important to our present purpose than mere description of this device is an account of what we have learned from its use. It taught us that marked increase of the target-skin and target-screen distance is worth going after because it reduces distortion, increases resolving power (fineness of detail in the screen image), and, when accompanied by an appropriate increase in the voltage factor, reduces quite spectacularly the biologic effects upon the patient's skin for a given degree of illumination at the screen (see Fig. 4 and Table I). How great is this reduction of skin effect can be learned from the following measurements. Operating the x-ray tubes at 6 ma. and 100 kv.p. (four-valve, full-wave rectified transformer), we found visibility relatively good, definitely superior to that obtained with commercially available fluoroscopes, and roentgen exposure at the patient's skin only 2.45 r per minute for the vertical ray and 4.45 r per minute for the horizontal ray.[4]

When we increased the distance, as a result of our anxiety to avoid crowding the "head holder" during bronchoscopic procedures, we felt that the highest energies that we could possibly impose upon even the water-cooled tube in the open air would be inadequate from the standpoint of illumination of the screen. We therefore installed a push-button control at the fluoro-

[4] I once measured the exposure at the patient's skin in more than twenty fluoroscopes of conventional design, some of the horizontal type, some of the vertical type, and many of the tilting type, and found that with routine operating factors actually in use with these devices, usually 4 ma. but sometimes 5 ma., skin exposures varied from 20 r per minute up to as much as 48 r per minute. Not one commercially available model was discovered in this survey with less than 20 r per minute at the patient's skin.

Doctor Garland (17) made a similar survey in San Francisco and got a range of 8 to 18 r per minute. He states his figures, however, in the following words: "If the target-skin distance is 18 inches and a thin aluminum filter is used, the patient's skin gets from 8 to 18 roentgens per minute (as measured by the author on different installations)." It is reassuring to hear that there are commercially available fluoroscopes with as much as 18 inches between focal spot and patient's skin. In my own survey, made several years ago, the target-skin distances ranged from 11 to 14 inches, which probably accounts for the difference between Doctor Garland's findings and mine. Another instance of the effectiveness of increasing the distance factor in fluoroscopy, in reducing exposure of patient's skin, is afforded by a special installation we recently completed in connection with a tilt-table, involving a target-skin distance of 26 inches. With this device the r-per-minute at the patient's skin is relatively low (19 r per minute) even when the energy input is as high as 80 kv.p. and 8 ma.

scopic screen, enabling us to momentarily impose higher energies. Thus, while operating at 6 ma. and 100 kv.p., the fluoroscopist could press a button and elevate the voltage to 110 kv.p. while at the same time stepping up the current to 18 or 20 ma. Even with the tube hot and water boiling we found it possible to impose such energies for two or three seconds at a time, without apparent danger to the tube. This stepping up of the energies increased the exposure at the patient's skin to approximately 14 r per minute for the horizontal ray and 9 r per minute for the vertical ray. It at once became apparent that when these high energies were utilized for one or two seconds at a time, a foreign body which was thus visualized often remained visible after a return to the lower energies. In other words, the brightness of the screen having been brought up to a high enough level so that better perception was possible, a return to the lower level of energy input (and screen brightness) did not result in a disappearance of the observed details. We now knew what we were looking at and it remained visible in a very reassuring way. From these experiences we developed the conviction that every fluoroscope should have on it some arrangement of push buttons to permit momentary activation at higher energy levels than would ordinarily be thought safe or appropriate. It has been our experience that, whenever a fluoroscope has been so equipped, it at once becomes the custom of its users to employ much lower energies than were formerly employed. In other words, having at hand, subject merely to the pressing of a button, higher energy levels than were formerly available, the fluoroscopist tends to make his standard foot switch setting at an energy level which is considerably lower than the one he would choose were he limited to a single setting. The installation of these remote control push-button devices, where the fluoroscopist can easily actuate them, thus becomes a safety factor both from the standpoint of the patient's skin and from the standpoint of the fluoroscopist's protection from scattered ray.

By this time some of you may be skeptical of the effectiveness of a fluoroscopic device which utilizes such high voltages and employs such unorthodox target-screen distances. What of the actual results? I must yield to the temptation to tell you the story of one of our biggest biplane fluoroscopic thrills.

A few months after we had finished our technical developments, and at a time when our confidence in the new device was growing steadily, Doctor Jackson received a letter from a bronchoscopist in another city. The gist of it was that a Mrs. R., age about 50, of a very thick and stocky build, had inhaled a very small and elusive straight pin and had wisely applied to have it removed. The pin was located in one of the smallest branches of the axillary basal segment of the right lower lobe, far down in the costophrenic angle, and its visualization was so difficult that fluoroscopically it was seen only in the vertical (P.A.) beam, and then only indistinctly.

Attempts had been made to remove the pin through the bronchoscope, but inability to visualize it with the lateral beam had prevented success. After the first two failures, it was thought that a different biplane fluoroscope might turn the trick and the case was transferred to another institution, but to no avail. Finally the assistance of a manufacturer was enlisted and a special biplane fluoroscope was improvised, using broader focus tubes so that the current could be increased, at least momentarily. This last attempt had also been unsuccessful, again due to the fact that the foreign body could be seen in only one plane. Upon learning that no further attempts at removal were contemplated, the patient had asked if she might go to Philadelphia to consult Doctor Jackson.

The letter emphasized the fact that the difficulty was *fluoroscopic*, not bronchoscopic, and apparently insurmountable. It closed with the suggestion that Doctor Jackson write a letter designed to save everyone time and trouble by explaining the futility of a journey to Philadelphia.

Doctor Jackson showed the letter to me

and I said: "Couldn't we please get the patient to come?" because, if there was a foreign body in a lung that could be visualized on roentgenograms yet not by fluoroscopy, we wanted it for its value as a sort of "test-object."

In due time, and after some additional correspondence, Mrs. R. arrived, accompanied by the bronchoscopist and the roentgenologist who had formed the original team. Incidentally, the roentgenologist was an old friend of mine and the bronchoscopist was, of course, one of Doctor Jackson's former students, and both were very welcome in our workshop.

I made everyone wait a full forty minutes for dark adaptation and when we were ready I was able to show them the shadow of the pin in both planes. The removal was quite dramatic, and soon accomplished. The necessary information as to the relationship of the point of the pin to the jaws of the forward-grasping forceps was readily provided by both beams of the fluoroscope. Under such circumstances the effect of Doctor Jackson's quiet precision is to give the impression that failure is utterly impossible. Our visitors gave us quite an ovation and we felt that our home-made biplane fluoroscope had won its spurs.

Another of our home-made fluoroscopic contraptions merits a brief description at this time (see Fig. 5). We call it our "multiplane fluoroscope," for it gives us a fluoroscopic beam which is rigidly confined to the lead glass protective shield at all times, but is nevertheless readily oriented in practically any direction, from almost any part of the room. Nicely counterweighted and freely movable on its ball-bearing travelling-crane support, this flexible device has become quite indispensable in our fracture work. As some of you know from seeing it in service, it has even given us fluoroscopic guidance for the insertion of the Smith-Petersen nail in cases of fracture of the femoral neck. The small size of its screen, 8 by 10 inches, and the statement that it is used in connection with fracture reductions, might provoke consternation among old and experienced radiologists. I can only say that our use of this device meets all the requirements of safety, not because of anything inherent in its design, but because of the way in which we operate it.

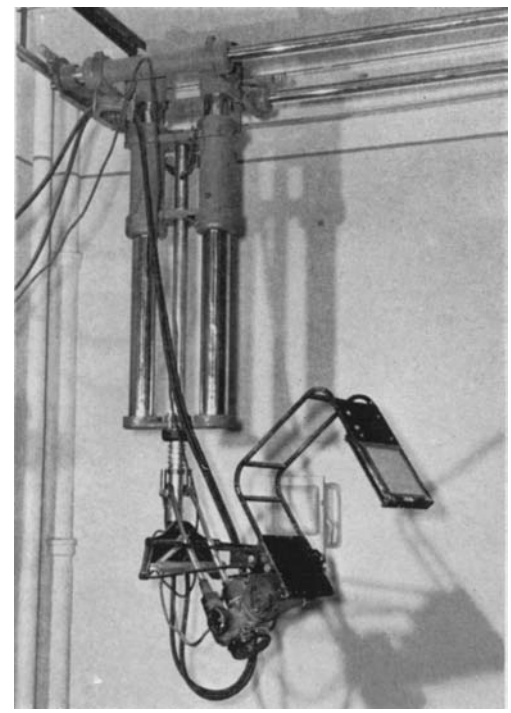

Fig. 5. This home-made "multiplane" fluoroscope at Temple University Hospital was designed particularly for visualizing fracture fragments before and after manipulation, but it has many other possibilities. Note the "traveling crane" type of ceiling mounting to permit free movement about the room. X-ray beam is readily angulated in any direction at the will of the operator. The C-shaped arm which connects tube housing and screen insures correct alignment of x-ray beam with lead glass protection. With this device we have been able to control the insertion of the Smith-Petersen nail in cases of intracapsular fracture of femoral neck.

In the first place, we never permit manipulation of a fracture while the x-ray beam is turned on. All manipulations are carried out with the x-ray turned off and with the room dimly lighted by yellow or red light. Between manipulations, or after a final adjustment, with the hands and other parts of the fracture surgeon and his assistants carefully removed to a place of safety, the fluoroscopic screen image is used as a "check-up." We have succeeded in training the fracture surgeons to look upon this

fluoroscopic glimpse as a safe procedure when carried out carefully, but an extremely dangerous procedure when used in the wrong way.

When this work began, and particularly when the flexibility of the multiplane fluoroscope had been developed to its present degree, there was a tendency for the fracture surgeons to dictate when the x-ray beam should be turned on and when it should be turned off. We realized at once that the radiologist cannot allow the fracture surgeon to subject his hands to the damaging effects of the primary beam just because he claims the right to accept that risk. The responsibility for the safety of all concerned is squarely up to the radiologist. That we succeeded in correcting this difficulty is due to two circumstances. The first was the arrival of some cases of roentgen injury to the hands. In one of these the sufferer, a fracture surgeon, a visitor from a distant city, came to us for advice on account of a roentgen ulcer on one of his fingers. Our own fracture surgeon and professor of orthopedics, Dr. John Royal Moore, was called upon to amputate the injured finger and he saw to it that the younger members of his staff were thoroughly informed as to the reasons for the amputation. When Doctor Moore and his staff submit to the discipline of complete avoidance of x-ray exposure, they know that the dangers we talk about are not purely imaginary.

The other factor that has aided us in enforcing the proper discipline is this. We have succeeded in convincing the fracture surgeons that reduction of fractures under fluoroscopic visualization would, even if it were not dangerous, interfere with their developing special skill as "bone-setters." We like to remind them that a blind man can imbibe from a bowl of soup without soiling his vest because he is habituated to his blindness, but if you or I were to blindfold ourselves we could be pretty sure that the soup would be spilled. In the same way, the fracture surgeon who practises his bone-setting in the moderately dim light of the fluoroscopic room with the x-ray beam turned off is learning something that he can put into practice when he is many miles away from x-ray apparatus. If, on the other hand, he should make it a practice to do his fracture reductions with the x-ray turned on, he would develop a tendency to become dependent upon the fluoroscopic image.

In view of the very satisfactory performance of this home-made "multiplane fluoroscope," with its shock-proof, oil-insulated, cable-connected x-ray tube, and its C-shaped member for maintaining alignment of x-ray beam and screen (and lead glass protection of screen), we have noted with interest some very similar features in the 1941 model of U. S. Army Field Unit. This ingenious development appeals to us as a move in the right direction, and its unique new x-ray tube, with air blower for cooling the housing and "impeller" for circulating the oil to convey anode heat out to the housing, has already made history. In this device, as in ours, the question of adequacy of x-ray protection has been raised. I think we must admit that such flexible devices as these are not *inherently* safe, and that it is up to the operator to adhere to a proper technic. After all, the direct beam is properly collimated, and it is the ray scattered by the patient's tissues that must be guarded against. This is a factor in practically every fluoroscopic procedure in clinical practice.

In this paper I have purposely avoided any attempt to cover the subject of x-ray protection. In the first place, it is a subject by itself, and a big one. In the second place, it has been thoroughly covered in many previous publications by men better qualified than I (2, 10, 11, 12, 13, 14, 15, 23, 28, 29, 44, 46, 52, 53, 56). For present purposes may I simply point out that the necessary instruments and methods of measurement are now available to all of us, so that no one need be in ignorance of the amount of ray he is accumulating, or its relationship to safe limits? X-ray equipment will never be fool-proof and any search for completely "safe" apparatus is bound to be futile. The proper training

of personnel and proper emphasis upon *methods of use* will always be necessary in fluoroscopy as in other branches of the practice of radiology.

Ponthus (40, 41, 42) has outlined a possible method of applying the principles of "body section roentgenography" ("planigraphy," "laminagraphy," etc.) to fluoroscopy. There is room for considerable doubt as to whether such a method will ever achieve practical success. According to the best information I have been able to obtain, neither Ponthus nor anyone else has actually tried the method with x-rays. (Ponthus built a model to illustrate the principle, using a beam of light instead of x-rays.) But the important place which this method's roentgenographic counterpart is making for itself in present day practice seemed to justify calling it to your attention. Figure 6 is taken from one of Ponthus' descriptions of the method.

Stereoscopy is such an important element in the armamentarium of the modern diagnostic roentgenologist that he must often ask himself why it has not been successfully applied to fluoroscopy. Many *theoretically* adequate stereoscopic fluoroscopes have been built, one of the earliest by Caldwell. Dumond (16) has given us a very complete exposition of physical and mathematical principles. Yet stereofluoroscopes continue to gather dust, or go to the junk heap, and none has ever established itself as of sufficient value to warrant its upkeep. The reason for this is inherent in the retinal physiology of the fluoroscopist and it is to this that we must now turn our attention.

The human eye, when used in the interpretation of a roentgenogram, viewed on a proper illuminator, is able to distinguish differences in the brightness of adjacent film areas when those differences are of the order of 1 or 2 per cent. The same eye, even when thoroughly or completely dark-adapted, may require a 20 to 40 per cent intensity difference for discrimination when the brightness is reduced to the low levels that prevail in many fluoroscopic procedures (see Fig. 15). Furthermore, along with the loss of intensity discrimination goes a comparable loss of visual acuity (see Fig. 16). Since both of these important capacities of the visual apparatus (*i.e.*, "intensity discrimination" and "visual acuity") are grossly altered by the sort of changes in the brightness level that are met with constantly in everyday clinical fluoroscopy, it follows that limitations in fluoroscopic visibility are largely a matter of retinal physiology, and the brightness

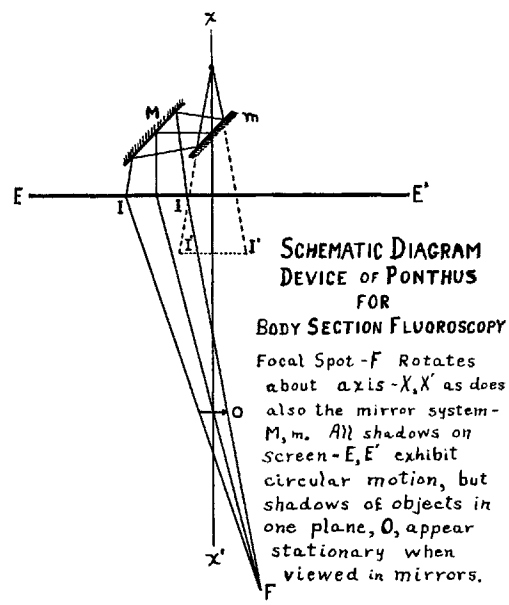

Fig. 6. The method of Ponthus for "planigraphic fluoroscopy," using circular motion. The method has not actually been tried except in the form of a model that employed a beam of light instead of x-rays. With this method the selection of the desired plane for the "cut" would be accomplished through adjustments of the relations of the two mirrors.

level is more important than any other single factor in the physical set-up.

Few radiologists are equipped to make determinations of the output of light by a fluoroscopic screen, in foot-candles, millilamberts, or any other unit of illumination or brightness, and until we know the brightness of the fluoroscopic screen image we cannot even guess as to how much "invisibility" or apparent "unsharpness" is due to the apparatus and how much is due to the inherent limitations of the retina.

This piece of paper held before you in the light of this reading lamp reflects light

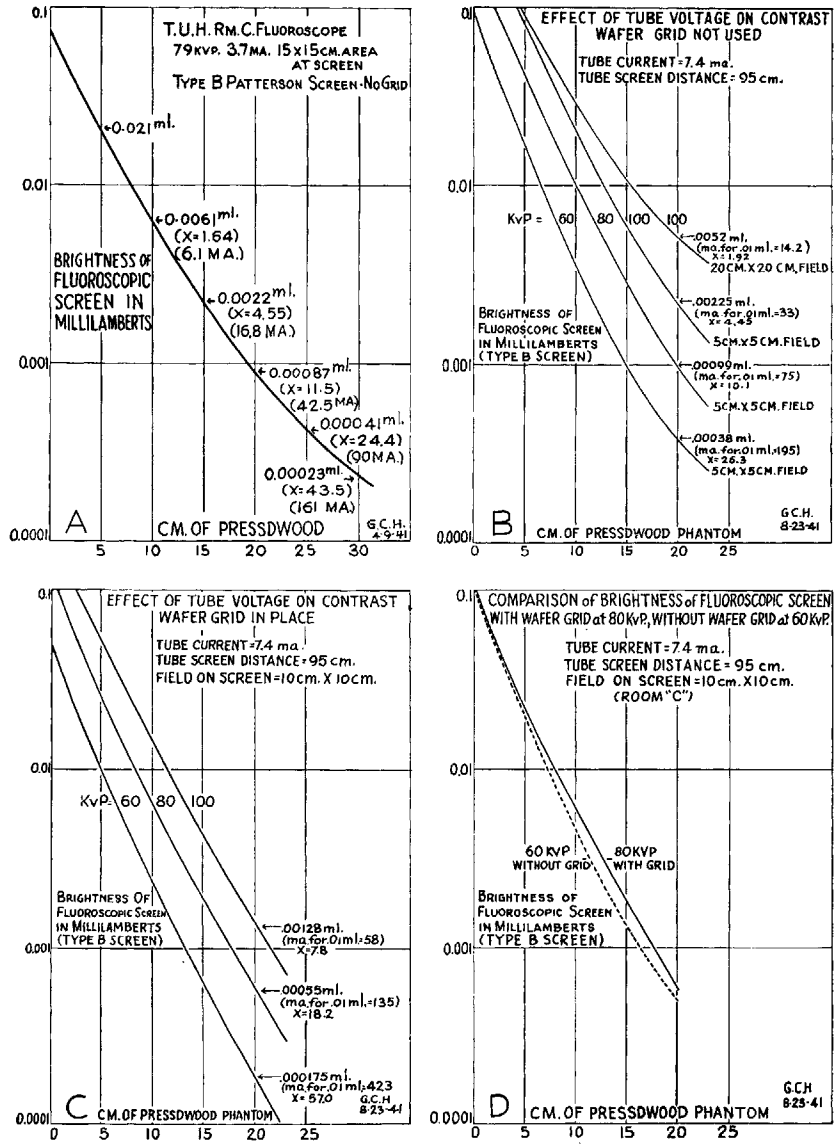

Fig. 7 A. The data were obtained with the Macbeth illuminometer (see Fig. 13). "Pressdwood" of 20 cm. thickness is equivalent to an abdomen approximately 17.5 cm. (7 inches) thick, on the average. Pressdwood of 10 cm. thickness is equivalent to lung field when thorax is approximately 20 cm. (8 inches) thick.

Below a brightness of 0.01 millilambert the retinal cones do not function at all and "visual acuity" and "intensity discrimination" are very poor (compare Figs. 15 and 16). On the graph, the various values given to "x" represent the factor which the intensity of the x-ray beam would have to be multiplied by, in order to raise the brightness to 0.01 millilambert. The milliamperage values given for thicknesses of pressdwood 10, 15, 20, 25 and 30 cm. represent the currents that would be necessary, with that particular fluoroscope, to produce a brightness of 0.01 millilambert.

B. The data of B, C, and D were obtained on a very different fluoroscope from those of A. The values given for "x" have the same significance, but are given only for pressdwood phantom thickness 20 cm.

C. A modern wafer grid was interposed between phantom and screen. The data indicate that the brightness level is seriously reduced through the use of a wafer grid and this renders the practice open to considerable question.

D. These graphs suggest that increase in contrast (represented by steepness of the absorption curve) can be obtained approximately as well through a reduction of voltage as through interposition of a wafer grid. But considerations of retinal physiology suggest avoidance of any measure which cuts down brightness.

at a brightness level of approximately 30 millilamberts. Dr. George C. Henny, to whom I am indebted for many of the original physical data which have made this analysis possible, has shown that under operating conditions in clinical practice the brightness of the Type B Patterson screen is of the order of 0.0001 to 0.01 millilambert (see Fig. 7). For example, in one particular case of a first-class modern fluoroscope operated at 80 kv.p. and 4 ma., 30 r per minute at the patient's skin, a 7-inch-thick abdomen reduced the brightness level to slightly less than 0.001 millilambert. This is 30,000 times dimmer than my piece of paper held here in the light of this reading lamp (see Figs. 7 and 8).

Some of you may be having difficulty in believing this last statement. You may be saying to yourselves that surely you would be aware of such a 30,000-fold difference if your particular fluoroscope were giving such low degrees of brightness. I can assure you that the statement is conservative, and that the reason you and I are unable to appreciate the magnitude of these differences in brightness with our own unaided senses is that our eyes adapt themselves to such changes in brightness by comparable changes in degree of retinal sensitivity. If a brightness of 0.001 millilambert produces an impression of being about one hundredth as bright as this piece of paper held in my hand, instead of the 30,000-fold difference that actually exists, it is because the sensitivity of the eye is thousands of times greater under conditions of complete or moderately complete dark adaptation than under conditions of complete or partial light adaptation.

The degree of sensitivity which the retina develops after a rest in the dark is something to marvel at. After ten or twelve hours in the dark, the threshold brightness reaches a lower limit of one millionth of a millilambert. Someone has recently calculated that the completely dark-adapted human retina, that is, the human retina in its most light-sensitive phase, produces the sensation of vision when but 8 or 9 photons impinge upon the sensitive elements. A single photon within the range of the visible spectrum is able to produce the necessary chemical change in one molecule of visual purple, and from determinations of light intensity at the threshold of vision, it appears that when 8 or 9 molecules of this remarkable compound are thus altered, the brain receives the appropriate stimulus through the optic tracts. This places the retina in a class with such sensitive physical systems as the Geiger counter and the electron multiplier. Yet that same retina, after exposure to

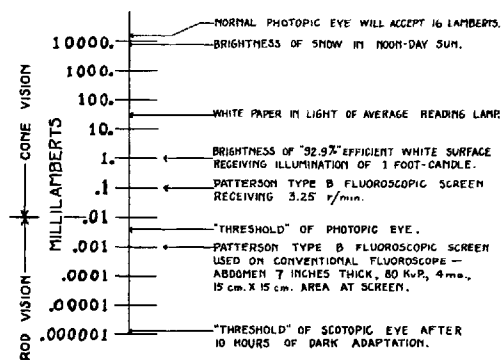

Fig. 8. On our scale we have indicated the change-over between rod vision (low brightness levels) and cone vision (high brightness levels) as though it occurred suddenly at 0.01 millilambert. The transition actually takes place more gradually, in the range between 0.01 and 0.1 millilambert. Even in the range between 1.0 and 0.1 millilambert, where cone vision is operative, deterioration in visual acuity and intensity discrimination with lowering of the brightness level, becomes very noticeable (compare Figs. 15 and 16).

bright light for three minutes, enters a state which we characterize as "light-adapted" in which its threshold (that is, the smallest amount of light which will produce the sensation of vision) has risen to 0.004 millilambert and it is capable of accepting, without injury to itself and with excellent transformation of these energies into the cerebral values of vision, energies as high as 16,000 millilamberts. In other words, its threshold has increased 4,000-fold, and the full range between energies that are acceptable by the completely light-adapted retina and the threshold of sensitivity of the completely dark-adapted eye is more than ten billion-fold (Fig. 8).

In a discussion of fluoroscopy it should

not be necessary to defend a full consideration of retinal physiology and the phenomena of dark adaptation and light adaptation, but experience shows that many users of fluoroscopes are uninformed or misinformed in these important matters. The fluoroscopist who begins an examination before an appropriate degree of dark adaptation has been achieved should at least have knowledge of just what he is throwing away in making that mistake. Without a thorough knowledge of the limitations of his own visual apparatus, the radiologist may be deceived into believing that "invisibility" is significant. A personal anecdote will serve to emphasize this point.

A good many years ago a young man, who has since become a very successful roentgenologist, held the privilege of making fluoroscopic studies in my department, and one day he and I entered the fluoroscopic room together. After a few minutes he signaled for a patient, and I remarked that I was not yet dark-adapted. He expressed surprise and said, "It's a pity that a man who does as much fluoroscopic work as you do, Doctor Chamberlain, has to wait so long for his pupils to dilate." I expressed the thought that perhaps his own visual apparatus was not free from certain known limitations and made a mental note that I must take the first opportunity to explain dark adaptation, which is, of course, very little concerned with dilatation of the pupil and very much concerned with sensitivity of the retina. In the meantime, however, I took advantage of the fact that a recent film of my abdomen had revealed a barium residue in my appendix, and I suggested to the young man that I would like to have him look at my appendix to see whether some barium sulphate which I had been given a few weeks previously was still present. I arranged myself on the fluoroscope and he looked for evidence of a barium residue and announced that there was none. I urged him to look closely because it had not been very long since a film showed the residue still there. He looked again, and again announced that barium residues were definitely not visible. By this time we had been six or seven minutes in the dark. I am sorry that I cannot give the exact time, but this attempt to visualize the barium in my appendix occurred between patients, and after he had completed at least one patient's fluoroscopy, and I think I am quite conservative in estimating six or seven minutes as the duration of the dark adaptation up to that moment. Ten or fifteen minutes later, after we had completed a number of fluoroscopic observations on a series of patients, I realized that my eyes were at last becoming dark-adapted and I suggested to the young man that I would like to have him look again to make perfectly sure that barium residues were not present in my appendix. He was obviously rather surprised at my request, as he was convinced in his own mind that further fluoroscopy was unnecessary and would reveal nothing. Imagine his surprise when this additional fluoroscopic observation brought to light, very vividly, a definite barium residue in my appendix. With this lesson before him, I think he was better able to appreciate the importance of dark adaptation. Unfortunately, unless great care is taken, there is always danger that absence of fluoroscopic evidence will be given too much weight. Fluoroscopy has inherent limitations even when the radiologist is completely dark-adapted. When we add to these inherent limitations the additional limitations imposed by a deficient dark adaptation, the deficit may add up to a formidable figure.

Physiologists and biophysicists have amassed a tremendous amount of information and knowledge concerning retinal physiology. Many of the more important items in this knowledge were well established eighty years ago. The first edition of Helmholtz' *Handbuch*, published in 1866, contained many of the fundamentals. Much of the information is well organized in textbooks of physiology and psychology, and excellent monographs such as the one by Selig Hecht in *Physiological Reviews*, April 1937 (21), have made

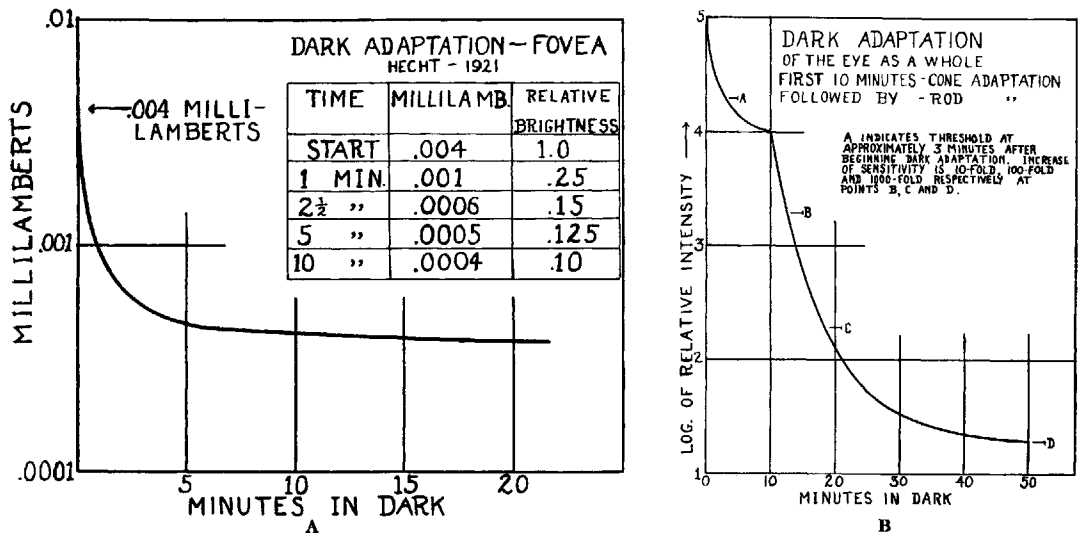

Fig. 9 A. Mistaken ideas concerning dark adaptation may result from disregard of certain fundamental facts. (1) The fovea contains no rods; (2) rods are the only elements which function at the extremely low brightness levels that obtain in practically all clinical fluoroscopy; (3) the early (first five minutes) and limited (approximately 10-fold) increase of sensitivity shown in this graph deals only with cone function.

B. Dark adaptation of the rods, obviously all-important in clinical fluoroscopy, begins to be measurable after approximately ten minutes in the dark. It is 100-fold between the ten- and twenty-minute measurements (at least 1,000-fold for the total twenty-minute interval though not measurable until rods become more sensitive than cones, which occurs at approximately ten minutes). Sensitivity continues to increase for many hours (compare Fig. 11), though not in comparable degree. Contrast the 1,000-fold increase during the first twenty minutes with the 5-fold increase during the second twenty minutes.

recent discoveries available to us. In spite of this, misconceptions are rampant. Very recently the science editor of the *New York Times* printed a terrible "break" about "dilatation of the pupil," making it obvious that he is entirely unaware of the changes in sensitivity that occur from instant to instant in the retina, and as recently as May 1941, in the *American Journal of Roentgenology*, we read in an article by Doctor Lerner (31): "It is likewise suggested that from three to five minutes is the optimum time the normal individual should spend in accommodation before roentgenoscoping. The increase in acuity after five minutes being so slight, it is felt that a longer time is not necessary." Contrast with this unfortunate misconception the following quotation from a remarkable pamphlet which was put out by the Committee upon Physiology of Vision of the Medical Research Council in London, England (1). On page 111 of this excellent review we read: "It is well known that in the early stages of dark adaptation (*e.g.*, the first seven minutes) the increase of sensitivity is very small in comparison with the rapid and marked increase which occurs for the ensuing half hour." Surely there must be some explanation for the discrepancy between Doctor Lerner's suggestion that it is unwise or unnecessary to spend more than three to five minutes in dark adaptation, and the very different data of the biophysicists and physiologists.

The explanation lies in the fact that Doctor Lerner's apparatus and method of plotting results (see Fig. 10-F) were not suited to the measurement of dark adaptation as it affects fluoroscopy. Whether or not his method gives reliable information concerning vitamin A deficiency I will leave to the experts in that field, though I must confess to some skepticism. The important point is that Doctor Lerner's graphs[5] show an approximately 10-fold increase of sensitivity in terms of the threshold of sensation, with the curve flattening out in three to five minutes. This is exactly what the physiologist always obtains if he

[5] The linear scale of threshold intensities used in plotting the data of Fig. 10-F tends to conceal the magnitude of sensitivity increase beyond the first 10-fold change. The log scales of Figs. 9-A, 9-B, 10-A, *et al.*, are more appropriate and informative.

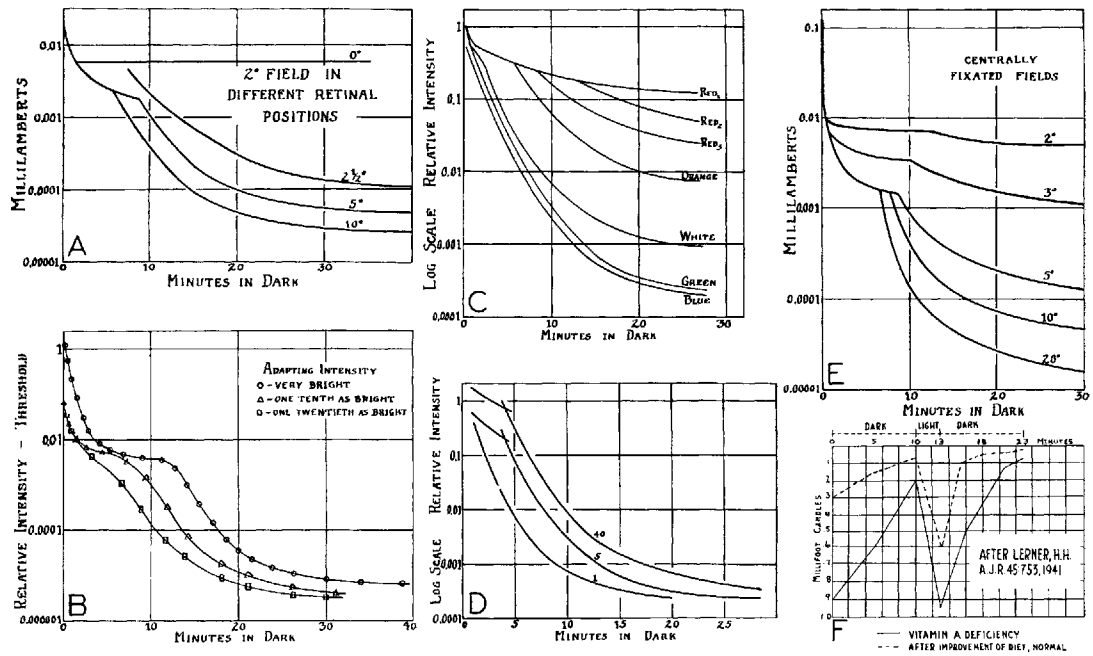

Fig. 10. The nature and degree of dark adaptation of the retina depend upon many factors such as (A) part of retinal field exposed to the testing light, (B) brightness of the "bleaching" light to which the retina was exposed before the beginning of dark adaptation, (C) the color of the testing light, (D) the duration of exposure to the "bleaching" light preceding the dark adaptation experiment, and (E) the area of retina exposed to the testing light.

F. From the preceding graph and a consideration of the data in Fig. 9 it is at once apparent that the method used for the data of Chart F has nothing to do with rod adaptation. Since clinical fluoroscopy is largely (often completely) a matter of rod vision, very different methods of study are required for conclusions regarding fluoroscopic vision (see text).

limits his measurements to cone function (see Fig. 9-A). But most clinical fluoroscopy is concerned with rod function, and until fluoroscopic screens are 100 times as bright as at present, the fact that the fovea centralis, where there are cones, no rods, becomes fully dark-adapted in from three to five minutes will hold little importance for the radiologist.

Retinal physiology, like retinal morphology, is very complicated. No two analyses of retinal function can be reconciled with each other unless we pay due attention to such diverse factors as the area of retina upon which the "bleaching light" impinges (both size and location of area with respect to fovea centralis, etc.), intensity of the illumination, duration of exposure, and color (of the bleaching light). Likewise the data are markedly altered by the corresponding factors in the light which is used for determination of the threshold. Figures 9, 10 and 11 have as their purpose a graphic presentation of the essential features of dark adaptation (and light adaptation) of the human retina. A few points require amplification.

The complete absence of rods from the fovea (Fig. 11-B) might lead one to expect an absence of cones from parts of the retina at a distance from the fovea, but such is not the case. Cones are present, though in varying proportions and concentrations, in all parts of the retina.

Color vision is a function of the cones. Rods are not concerned in color vision. (Physiologists have learned much by studies of retinal physiology in totally color-blind persons.)

Light of wavelength 6,700 to 7,000 Å. produces the sensation of deep red color through cone vision, but has no effect whatsoever upon the rods. This is important, for it signifies the possibility of obtaining complete dark adaptation of the rods while exposed to intensities of deep

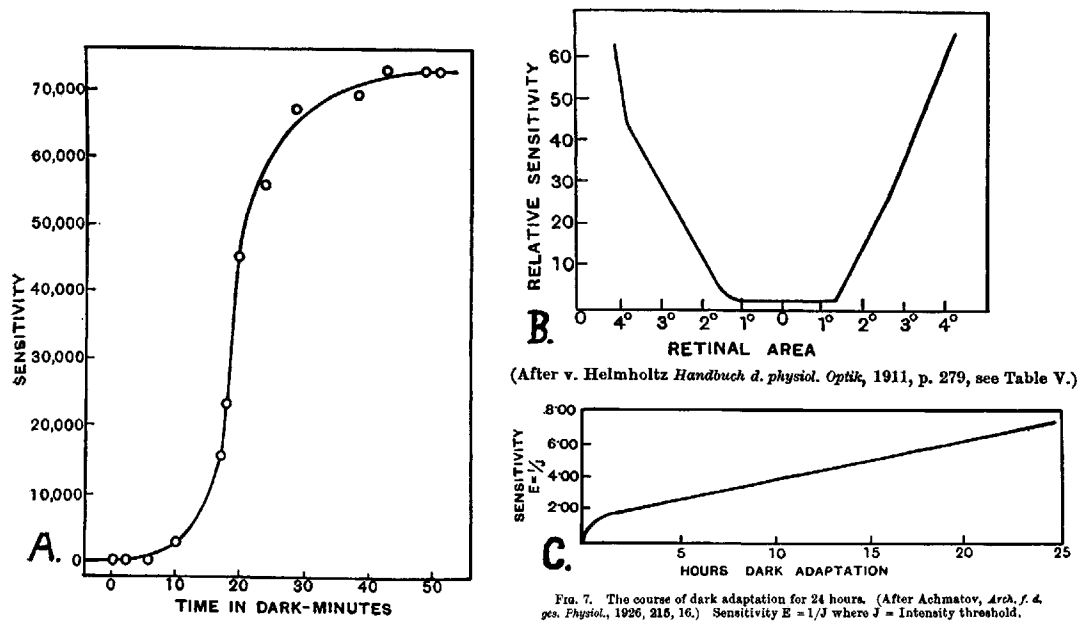

FIG. 7. The course of dark adaptation for 24 hours. (After Achmatov, *Arch. f. d. ges. Physiol.*, 1926, 215, 16.) Sensitivity E = 1/J where J = Intensity threshold.

Fig. 11. Further studies of retinal sensitivity and dark adaptation, taken from Adams (1).
A. This graph (credited to Hecht) is plotted from data similar to those of Fig. 9-B, sensitivity being defined as the reciprocal of the threshold intensity.
B. The absence of rods from the foveal area accounts for the findings charted here, a graphic representation of the "central scotoma" which accompanies vision at brightness levels below the threshold of cone vision.
C. Dark adaptation continues even after several hours, but for obvious reasons this fact is of little importance to the clinical fluoroscopist.

red light sufficient for useful work. By the use of appropriate filters and light source, the clinical fluoroscopist could dark-adapt his eyes without going through the ordeal of complete idleness that has plagued him these many years; if especially radiolucent parts are under scrutiny, so that brightness levels sufficiently high for cone vision are obtainable (above 0.013 to 0.014 millilambert) (see Fig. 7), a wait of three to five minutes would be ample (see Fig. 9-A); for all thicker parts (brightness levels too low for cone vision) adaptation would be complete without even that delay. For graphic evidence of these peculiarities of rod (colorless) and cone (color discerning) vision, see Figs. 12 and 10-C. This insensitiveness of the rods to deep red light, of wavelength longer than 6,700 Å., accounts for the fact that in a flower garden at twilight, red flowers appear black while the sense of brightness is still forthcoming in the yellows, greens, and blues.

Thus far we have allowed the emphasis to rest upon measurements of threshold intensity. But the really important factors for the clinical fluoroscopist are "intensity discrimination" and "visual acuity," corresponding roughly to "contrast" and "sharpness" in roentgenograms. Figures 15 and 16 serve to visualize the degree to which these features of retinal physiology ("intensity discrimination" and "visual acuity") deteriorate as a result of lowering of the brightness level. A careful study of these graphs suggests that the deterioration of intensity discrimination is more serious than that of visual acuity. Our experiences with Doctor Jackson's cases of metallic foreign body bear this out. Remarkably small objects can be seen if their shadows are very contrasty. But most measurements of visual acuity (*e.g.*, the data for Fig. 16) are based upon contours with maximum contrast, to all intents and purposes black on white or white on black, and many of the details in a lung field or abdomen are far less contrasty. In actual practice, therefore, we suffer from a combination of these two handicaps. Small wonder that stereofluoroscopy has failed, for stereoscopic vision depends upon perception of detail to an extent that is simply not forthcoming under conditions of clini-

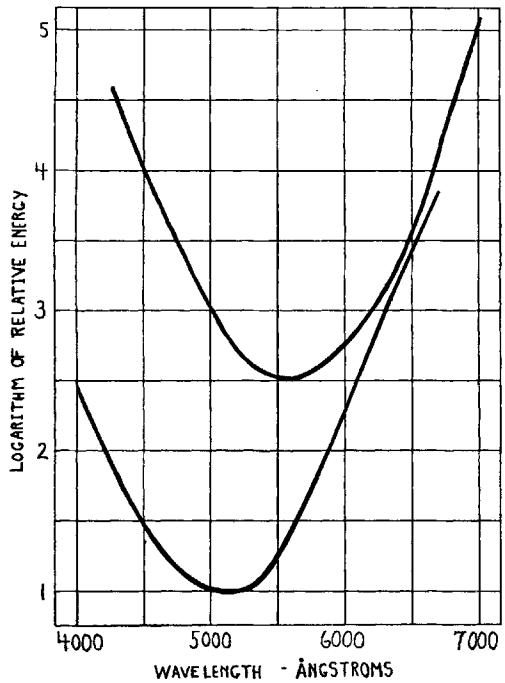

Fig. 12. After Hecht (21) to show the relation between wavelength and relative energy required to produce a specific visual effect at high (cone vision) and at low (rod vision) brightness levels. Note particularly the "blindness" of the rods at wavelengths longer than 6,700 A. Note also that the two curves are nearly coincident at the red end of the spectrum (compare Fig. 10-C).

cal fluoroscopy. Demonstrations of stereofluoroscopy using metallic objects, such as wire cages, are extremely misleading, and give no correct idea of what the results will be when (*a*) the objects being looked for are non-metallic and hence less contrasty, (*b*) the brightness levels are reduced from the 0.1 to 0.5 millilambert that is attainable with a model made of bare wires, down to the 0.01 to 0.001 millilambert that is forthcoming during clinical fluoroscopy. (Doctor Henny's data for Fig. 4-C indicate that brightnesses of 0.1 to 0.5 millilambert are forthcoming from a Patterson Type B screen when it receives 3.25 to 16.3 r per minute.) The present status of stereofluoroscopy might be summarized in these words: Rod vision is simply not competent for stereoscopy. When brightness levels in clinical fluoroscopy reach 100 times their present values, it will be time to build another stereofluoroscope.

In order to apply the knowledge set forth in the graphs of Figs. 15 and 16 to the problem of clinical fluoroscopy, Doctor Henny measured the brightness of the Type B Patterson screen with the Macbeth illuminometer (see Fig. 13), on a number of different fluoroscopes, using various voltages and current intensities, and with a wide variety of thicknesses of pressdwood phantom. The results are embodied in the graphs of Fig. 7. For the data of Fig. 7-A, a conventional model of fluoroscope was used, in which the target-skin (table top) distance is but 11.2 inches. In contrast to this, the home-made fluoroscope with which the data of Figs. 7-B, 7-C and 7-D were obtained utilizes a target-table top distance of 26 inches. The x-ray tube is cable-connected, oil-insulated, and with the manufacturer's permission we have installed an oil pump, oil reservoir, and flexible neoprene tubings to provide positive circulation of the insulating oil. We are thus able to operate this tube at energy levels as high as 10-15 ma. at 100 kv.p. As the graphs indicate, the brightness levels are higher with this fluoroscope (at a given thickness of the phantom) than with the conventional model, in spite of a lower r-afflux at the patient's skin.

But "visual acuity" and "intensity discrimination" such as the radiologist enjoys while examining films on a good illuminator, would require brightness levels 10,000 to 30,000 times those that obtain in clinical fluoroscopy (Figs. 15 and 16). Even if we compromise on a brightness level as low as 0.1 millilambert, which is 100 to 3,000 times lower than the film reading range, we would be forced to operate our fluoroscopes at currents of 400 to 1,600 ma. (800 to 3,000 r per minute at the patient's skin), an obvious impossibility. In other words, no conceivable change or improvement in the present type of fluoroscope offers the possibility of producing a really satisfactory rise in the brightness level.

Faced with the apparent impossibility of raising the brightness of the present day fluoroscope to a level that would enable it to compete with the roentgenogram, we naturally turn to the question of whether

some intermediate degree of improvement may not be possible. On some of the graphs of Fig. 7 I have indicated the currents that would be required in order to produce brightness levels of 0.01 millilambert, ten times lower than the level referred to in the preceding paragraph (1,000 to 30,000 times lower than the film reading range). I chose the value 0.01 millilambert because that is given by some physiologists as approximately the level at which cone vision begins. As a matter of fact, the most recent work on this subject indicates that the change-over from rod vision (low intensity) to cone vision (high intensity) begins between 0.013 and 0.014 millilambert. Furthermore, the transition is gradual and the arrows which I have placed at the 0.01 millilambert level of Fig. 16 are hardly justified in view of the known facts concerning this transition from scotopic vision (the dark-adapted eye) to photopic vision (the light-adapted eye).

In spite of the fact that a brightness level of 0.01 millilambert is devoid of any spectacular significance, it possesses at least the quality of being attainable under some of the conditions of present day clinical fluoroscopy. At the same time its superiority over the lower levels which we are accustomed to putting up with is very noticeable. I think we can translate this statement into terms of actual experience if we recall the relatively good vision we enjoy on those rare occasions when we fluoroscope the lung fields of an unusually thin patient. Referring again to Fig. 7-A, we note that this graph was obtained with a very ordinary and conventional type of fluoroscope and that a brightness level of 0.01 millilambert was reached when the phantom of pressdwood was thinned down to approximately 8 cm. As reported elsewhere in this paper, a thickness of 8 cm. of pressdwood has approximately the same effect upon the fluoroscopic x-ray beam as a patient's thorax of thickness 16 cm. (a little over 6 inches). In soft tissue regions, elsewhere than over lung fields, a part would have to be a little less than 7 cm. thick in order to absorb the x-ray beam to the same degree as the 8 cm. thickness of pressdwood.

Fig. 13. Photograph of the Macbeth illuminometer as used by Doctor Henny. The pressdwood phantom was 20 cm. thick at the moment the photograph was made. The individual sheets have a thickness of 0.67 cm. Care was taken to insure maintenance of a constant target-screen distance when the thickness of the phantom was varied.

By referring to the third graph of Fig. 7-B (100 kv.p., 5 cm. by 5 cm. field) we note that, owing to improved characteristics and higher voltage, a brightness level of 0.01 millilambert is attainable when the pressdwood phantom is as much as 13 cm. thick, the tube current being 7.4 ma. (27.4 r per minute at the patient's skin). At the present moment additional studies are under way, with a view to learning whether further improvement along the lines suggested by comparison of Figs. 7-A and 7-B may be possible. Actual experience with our home-made biplane fluoroscope suggests that it is, as do also the findings set forth in Fig. 4 and Table I.

Pressdwood is a very convenient material for phantom work. We have no reason to believe that its effective atomic number is different from that of human tissue. Its density is, however, slightly

different than that of the average human abdomen. We carried out a series of measurements of the brightness of the Type B Patterson screen during clinical fluoroscopy of a series of carefully measured abdomens and thoraces. We understand that there are types of pressdwood ("pressdwood" is a trade name for a particular kind of "wall board") which differ in density from the kind we are using. Ours weighs 0.975 gram per cubic centimeter.

There is a good deal of variation among individual human beings. For each centimeter of abdominal thickness, the equivalent thickness of pressdwood varied from 0.95 cm. to 1.35 cm. with an average value of 1.16 cm. For example, the average abdomen measuring 17 cm. thick will have the same effect upon the x-ray beam as 19.8 cm. of the pressdwood.

For each centimeter of thoracic thickness, the equivalent thickness of pressdwood varied from 0.44 cm. to 0.64 cm. with an average value of 0.5 cm. For example, an average thorax measuring 25 cm. in thickness will have the same effect upon the beam as 12.5 cm. of pressdwood.

The technical excellence of the modern American-made "wafer grid" has led us to pay special attention to the possibility of improving fluoroscopic visibility through its use. In Fig. 7-D we present some theoretical and physical evidence, and it must be admitted that, within the range which we have thus far studied, this evidence is against the use of the wafer grid. The decrease of brightness caused by the grid is seen to be approximately equal to that caused by the lowering of the voltage from 80 kv.p. to 60 kv.p. In view of the obvious advantages, to patient and fluoroscopist, of cutting down skin exposure and scattered ray, these findings would appear to favor a lowering of the voltage rather than the application of a wafer grid for the accomplishment of an increase in contrast. There is another side to this question, however. I do not believe that our studies have proceeded far enough to enable us to draw final conclusions. In the first place, what is true in the range between 60 kv.p. and 100 kv.p. may not apply at voltages of 120 to 140 kv.p. We have not yet satisfied ourselves that a combination of considerably increased voltage and a wafer grid might not bring us much needed improvement. Secondly, there is a definite place for studies of a more empiric type in this field. In addition to further studies with the Macbeth illuminometer, in which the steepness of the absorption curve in pressdwood represents contrast, and brightness is measured in definite units, we plan to carry out investigations with special phantoms designed to reveal empirically the validity of various changes in the technical factors.

A number of investigators have devised phantoms that give more or less significant tests of what might be termed fluoroscopic effectiveness. Burger and Dijk (4, 5, 6) have done particularly good work along these lines. They drilled holes in bakelite, varying the diameters of the holes (for measurement of "visual acuity") and the thickness of the bakelite (for determination of "intensity discrimination," since the thicker the bakelite in which the holes were bored, the greater the "contrast"). The drilled pieces of bakelite were then mounted between other sheets of bakelite and a phantom was thus made up.

We have had some success with pieces of pressdwood (and bakelite, where the texture and strength of the pressdwood were not satisfactory for fabrication). Fig. 14-B shows the appearance of our phantom when it is quite thin. As succeeding layers of pressdwood are added, bringing the brightness down to the levels met with in clinical work, the smaller holes and smaller "buttons," representing, respectively, the negative and positive shadows that are met with clinically, begin to disappear. The largest markings remain visible after all of the smaller ones have disappeared, in the order of their size.

In using such a phantom for comparisons of different fluoroscopes, or different fluoroscopic technics, one sometimes wishes to emphasize the factor of "visual acuity,"

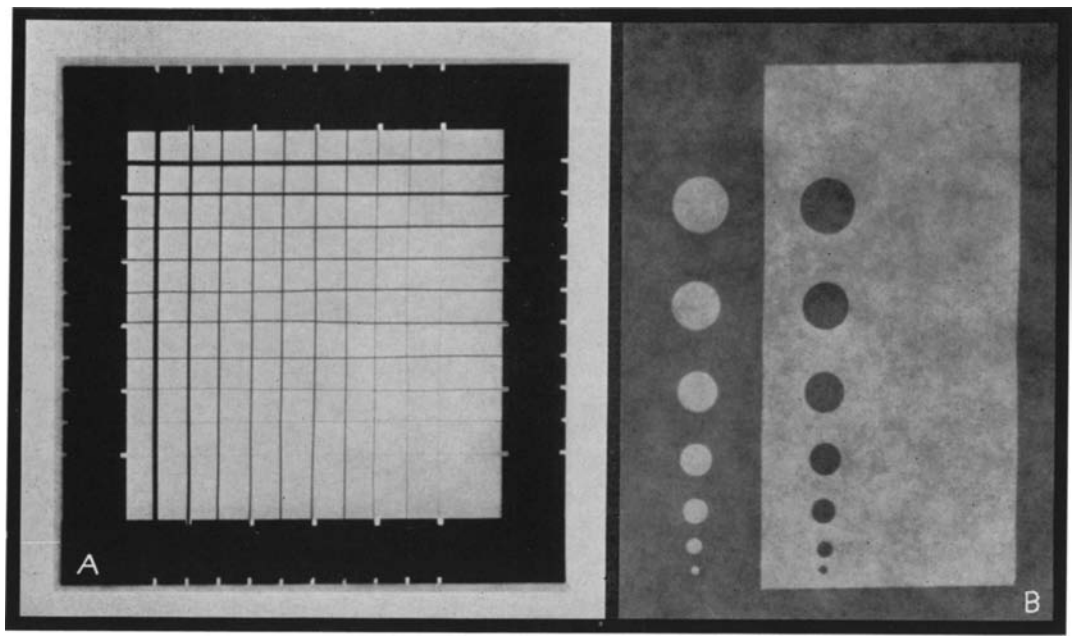

Fig. 14. Many observers have used phantoms for the purpose of evaluating the physiologic limitations of fluoroscopic vision.

A. Ten wires have been stretched in both directions across the 4 inch × 4 inch aperture of a square metal frame, diameter of the wires decreasing progressively from 0.04 to 0.003 inch. With such a wire mesh buried in a paraffin and pressdwood phantom we have demonstrated to ourselves the loss in visual acuity which occurs at low brightness levels. For purposes of comparing different fluoroscopes, such a phantom has the advantage of combining evaluation of inherent unsharpness due to focal spot size, etc., with evaluation of loss of visual acuity at the particular brightness level afforded by the particular fluoroscope under study.

B. "Soft tissues" are more frequently under fluoroscopic scrutiny than metallic particles. The phantom here shown imitates "negative shadows" (holes of varying diameter drilled in a layer of pressdwood, shown on the left) and "positive shadows" (buttons of pressdwood of thickness 0.67 cm., placed within a 5 cm. × 10 cm. × 0.67 cm. air space, shown on the right) at the brightness levels that prevail in clinical fluoroscopy. As in the case of the wire mesh, the studies are carried out with varying thicknesses of pressdwood behind and in front of the "detail."

without regard to the factor of "intensity discrimination." For this purpose we have constructed a composite plate for use with the same pressdwood phantom, in which a series of wires of decreasing diameter are stretched on a metal frame and embedded in paraffin (Fig. 14-A). The 8 wires of each set have the following approximate thickness in inches, from largest to smallest: 0.04, 0.025, 0.016, 0.014, 0.0125, 0.011, 0.009, 0.0065, 0.005, 0.003 (purchased in "American wire gauge" sizes as gauge 18, 22, 26, 27, 28, 29, 31, 33, 36, 40).

Good work is possible with phantoms of both types, especially in the direction of determining limitations, at various patient thicknesses, with different fluoroscopes, or different settings on the same fluoroscope.

Time does not permit an excursion into the chemistry and physics of the fluoroscopic screen. For my bibliography I have selected some items of general interest to the radiologist (25, 32, 33, 50). Attention is called particularly to the contributions of Levy and West, the British originators of the screen we now know as the Patterson Type B.

Doctor Henny has studied the Patterson Type B screen exhaustively and from time to time will doubtless contribute articles on special phases of fluoroscopy. He has shown that fluoroscopic screens, like intensifying screens, possess a "temperature coefficient." With a constant intensity of bombardment by x-rays a Patterson Type B screen gives out more light as its temperature is lowered. Exact measure-

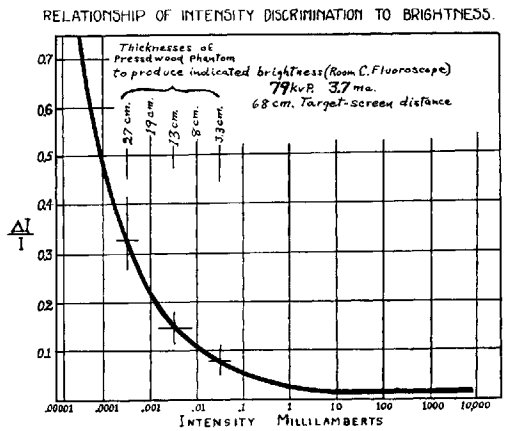

Fig. 15. The curve is from the data of Hecht. Intensity discrimination ($\Delta I/I$) is expressed as the fraction by which a given light intensity must be added to in order for the difference to be visible at that particular brightness level. We have indicated on Doctor Hecht's curve the particular thicknesses of pressdwood phantom that will produce the particular brightness levels we have indicated. Thicknesses of pressdwood phantom can be translated into corresponding thickness of a human abdomen, by applying a factor of 0.86.

ments indicate that the temperature coefficient of the fluoroscopic screen is very much smaller than that of the Par Speed Patterson intensifying screen used with x-ray film. In other words, a lowering of the temperature by any given amount produces a relatively slight increase in the brightness of the fluoroscopic screen but a relatively greater increase of density of an x-ray film exposed between Par Speed intensifying screens. It is obvious that no practical value or clinical importance attaches to this quality of the fluoroscopic screen as at present used. Room temperatures do not vary enough to make any real difference in the performance of screens during clinical fluoroscopy. Results up to date, in the limited range of temperatures at our disposal, have not suggested that the gain in brightness obtainable from operating screens at very low temperatures would be great enough to justify the development of the necessary equipment for maintaining low temperatures at the screen in the presence of tolerable room temperatures.

A very practical result of Doctor Henny's researches is set forth in Fig. 4-C. It appears that within the range of voltages ordinarily used for clinical fluoroscopy the relationship of r per minute to screen brightness is approximately linear. We have reason to believe that with very intense x-ray beams a falling off in brightness will be found. In other words, it appears that regardless of voltage (within ordinary clinical ranges) 0.31 r per minute reaching the screen will produce a brightness of 0.01 millilambert, 0.62 r per minute will produce a brightness of 0.02 millilambert, but 3.1 r per minute will produce slightly less than 0.1 millilambert and 31 r per minute might be expected to produce measurably less than 1.0 millilambert. This is not surprising since there is no reason to believe that fluorescent materials are capable of unlimited increase of their output of fluorescent light with increase of excitation by x-rays or other forms of energy. Doctor Henny is continuing studies and will report later upon the voltage factor outside of the range reported upon here. He has already discovered that the independence of the voltage factor, which is indicated in the graph of Fig. 4-C, is not present as we continue to increase the voltage above the figures ordinarily used in clinical practice.

The important thing about the data of Fig. 4-C is that they make it possible for the clinical fluoroscopist to carry out scientific studies of his own apparatus without the necessity of equipping himself with a Macbeth illuminometer. With a Victoreen thimble chamber and a phantom of pressdwood he can determine the r per minute reaching the screen at various thicknesses of patient. Reference to the data indicated in Fig. 4-C will enable him to translate his figures for r per minute at the screen into terms of brightness in millilamberts. One of the principal aims of this paper is to persuade the clinical fluoroscopist to measure the limitations under which he is working in particular situations. Surely he should know just how poor are his intensity discrimination and visual acuity (*a*) when fluoroscoping an especially thick abdomen, (*b*) when fluoroscoping an average abdomen, (*c*) when fluoroscoping an average thorax, etc. With an r-meter,

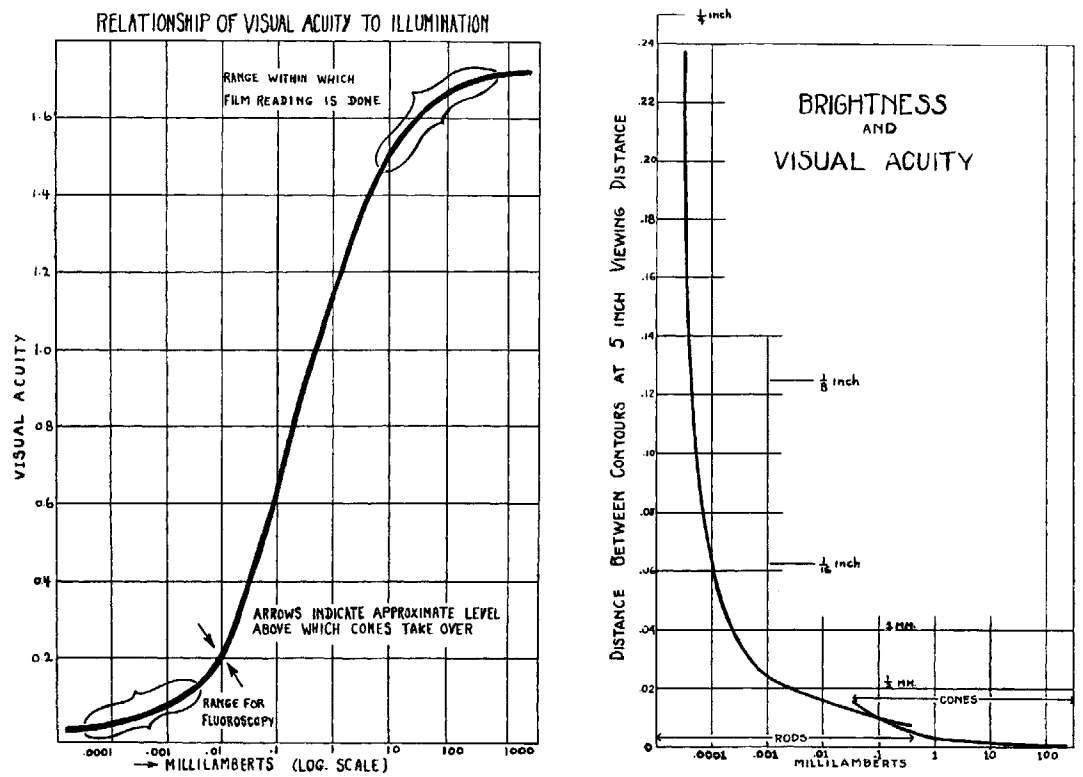

Fig. 16. Visual acuity is defined as the reciprocal of the angular distance which must separate two contours in order that they may be recognized as discrete, the unit of separation being one minute of arc. The graph on the left is after Hecht (20), and we have indicated with brackets the approximate ranges of brightness within which film reading and clinical fluoroscopy ordinarily occur. Our indication (arrows) of the boundary between rod vision (low intensity) and cone vision (high intensity) is open to question because the change-over does not occur suddenly and a far more important feature of retinal physiology is indicated by the steepness of the curve in the range between brightness 1.0 and 0.01 millilambert.

The curve on the right is our own, but is based entirely upon Hecht's graph of visual acuity at various brightnesses of green light (see Fig. 25, page 271 of Hecht, 21). Instead of plotting "visual acuity" we have based our graph directly on the "separation between contours" upon which the definition of visual acuity depends.

a pressdwood phantom, the data of Fig. 4-C, and reference to the findings of the biophysicists and physiologists as summarized in Figs. 15 and 16, he can give meaning to the situation that confronts him in the fluoroscopic room.

The clinical radiologist who carries out the above suggestions will gain a new insight into one of the most important elements in his armamentarium, fluoroscopy. He will be surprised at the extraordinary degree to which the fluoroscopic x-ray beam is absorbed in the patient. With the average fluoroscope of conventional design and modern manufacture, an abdomen 10 inches thick will permit as little as one part in 2,000 of the incident beam to reach the screen. In other words, in order for 0.015 r per minute to reach the screen (producing a brightness of approximately 0.0005 millilambert), the incident beam at the patient's skin must have an intensity of the order of 30 r per minute.

The modern fluoroscopic screen provides a wealth of detail and excellent contrast. When photographed with precision, it yields an amazing result, amazing chiefly because we have tended to think of the inadequacy of clinical fluoroscopy as in some way inherent in the apparatus. Actually it has always been inherent in the functional limitations of the human retina.

Suppose that the detail and contrast that are present on the fluoroscopic screen were as visible to the radiologist as the images on good roentgen films. Under such circumstances a fluoroscopic study would be tantamount to viewing thousands

of excellent roentgenograms in cinematographic sequence—roentgenograms made at all possible phases of functional movement and in any or all selected angles of projection. The present day x-ray film would be unable to compete with such a device and one cannot but believe that normal and morbid physiology would become as much the province of the radiologist as anatomy and gross pathology already are.

From a consideration of retinal physiology (*vide supra*) it is apparent that what is needed for the realization of such a revolutionary change in clinical fluoroscopy is not simply a 10-fold or 100-fold increase of brightness. An increase of the order of 1,000-fold would be required. What is the likelihood that such may be forthcoming?

In my own opinion it is just around the corner and when it comes it will put medicine and radiology through another revolution, not very different from that which followed the advent of roentgenography and present-day fluoroscopy at the turn of the century. That it is on the way is attested to by the measure of human achievement recently attained in the fields of the electron microscope and the television transmitter.

A few months ago it was my privilege to view the fluoroscopic screen of the R.C.A. electron microscope in Camden, New Jersey (35). Magnetic lenses focus electron beams exactly as glass lenses focus beams of light. The electrons used in the R.C.A. electron microscope have frequency characteristics that make them equivalent to photons of wavelength approximately 1,000 times shorter than the wavelength of visible light. This gives it a greater resolving power, and magnifications as high as one hundred thousand have been accomplished by adding photographic enlargement to the magnification obtained directly in the microscope itself.

In the electron microscope (Fig. 18), the electron beam which originates from the "electron gun" is converged by a magnetic lens coil corresponding to the condensing lens in an optical microscope. The condensed electron beam is focused upon the specimen that is under observation. The rays of electrons which emerge from the specimen in the direction of the observer are now focused by other magnetic lenses, so as to form the highly magnified image. This image is made visible by causing it to strike a fluorescent screen. (Even when the objective is a photomicrographic film, the focusing and field selection are accomplished with the fluorescent screen.) It seems perfectly obvious to me that similar principles can be invoked for fluoroscopy. This has already been done in the case of television.

In a television camera the light from the camera lens is focused upon a sensitized surface which gives off electrons in proportion to the intensity of the impinging light. The electrons thus given off form what is technically known as an electron image. Were we to allow an x-ray beam to impinge upon the same sensitized surface, instead of the focused light from the photographic lens, we would also obtain an electron image. The electron image of the "televisor" is focused by magnetic lenses and the next step, in the case of television, is the scanning of the electron image. In the carrying out of this procedure of scanning, all but one-hundredth of one per cent of the energy in the electron image is discarded, for at any given moment the only electrons that are utilized are those which enter an extremely small aperture, the area of which is certainly no greater than one part in several thousand relative to the total cross-section of the electron beam. The reason that this minute fraction of the total energy is adequate for purposes of television transmission is that, after the electron image has been formed by the action of radiation upon the sensitized surface, the electrons are subjected to a voltage differential which accelerates them and, by the time they reach the opposite end of the televisor tube, they contain a great deal more energy than they contained when they started. The principle is the same as that in the hot cathode x-ray tube, in which the energy of the electron beam that bombards the focal spot is due to the difference of

potential between the cathode and anode.

When we begin to apply the principles of television and the electron microscope to the problem of fluoroscopy, we will not discard 99.9 per cent or more of the energy in the electron image beam, because we will not be under the necessity of scanning the image. We have but to focus it on a fluorescent screen at the opposite end of the accelerator tube from the sensitized plate where the electron image was formed. Whether or not we will make use of the ability to alter the size of the image, I do not know, but I presume that we may sometimes contrive to increase our brightness levels by reducing the image to dimensions considerably smaller than those at the original sensitized surface. At other times we may wish to produce varying degrees of enlargement of the image. It is conceivable that this may be accomplished simply by the operation of a current regulator in the circuit that supplies the magnetic coils of the lens system.

I cannot refrain from mentioning some economic facts that may be pertinent. A batch of 5 electron microscopes has been produced at the Camden works of the R.C.A. The list price is $9,400. The device is quite elaborate, and under all of the circumstances a price of $9,400 is remarkably low. Nevertheless, if these microscopes were produced in quantities the price would be a great deal lower. The most expensive single feature of such a device, as I see it, would be the stabilizer for the magnetic lens current supply and voltage supply for the accelerator tube. In the R.C.A. electron microscope the regulation of the voltages and current is so important that the supply must be stabilized to within approximately one part in sixty thousand.

When these principles have been harnessed for the use of the fluoroscopist, he will have a very different method from the one now available. Our interest in the roentgenogram will dwindle. There is much talk of the "value of a permanent record" and we have got into the habit of thinking that such permanent records as we obtain on roentgenograms are important. As a matter of fact, when you and I go to see our family doctor or become patients of famous internists, we are not concerned over the fact that photographic recording of the findings is not a part of his armamentarium. The fluoroscopist will need to be highly trained. (Perhaps the radiologist will come back into his own when the records cease to be bandied about as x-ray films are today.) When he is studying a patient he will have the equivalent of literally thousands of roentgenograms, because he will be able to rotate the patient into various positions and nothing that can now be shown on roentgenograms will escape his powers of observation. Does anyone believe that such an outcome is impossible of attainment? Surely no one, in view of what has been accomplished in these neighboring fields. Dr. Irving Langmuir, of the General Electric Research Laboratories in Schenectady, has already made a beginning (see Fig. 18).[6]

Doctor Langmuir's patent was granted nearly three years ago. Judging from the usual experience, his application must have been filed about two years before the patent was granted. In view of the achievements of the physicists and engineers in the R.C.A. Victor laboratories at Camden, and in other research laboratories where successful electron microscopes have been built, it is a little hard to understand the delay in the creation of a practical device for the acceleration of electrons in an electron image of fluoroscopic origin. Perhaps what is needed is a realization by the physicists and engineers of the great need for

[6] On Jan. 20, 1942, U. S. Patent 2,270,373, covering a "Neutron Image Converter," was granted to Hartmut I. Kallmann of Berlin-Charlottenburg and Ernst Kuhn of Berlin, Germany, assigned by them to I. G. Farbenindustrie Aktiengesellschaft, of Frankfurt am Main. The diagrams which accompanied the application indicate a beam of neutrons striking a sensitive surface after traversing a human body in the manner of a fluoroscopic x-ray beam. "Charged particles or electrons" which emanate from the sensitive surface or "neutron reactive layer" are then accelerated by an electrostatic field and focused on a fluorescent screen by either an electrostatic lens or an electromagnetic lens. (A "second stage" of amplification by electron acceleration is indicated on the diagrams. This second stage appears to be identical with the device of Langmuir as shown in Fig. 18.)

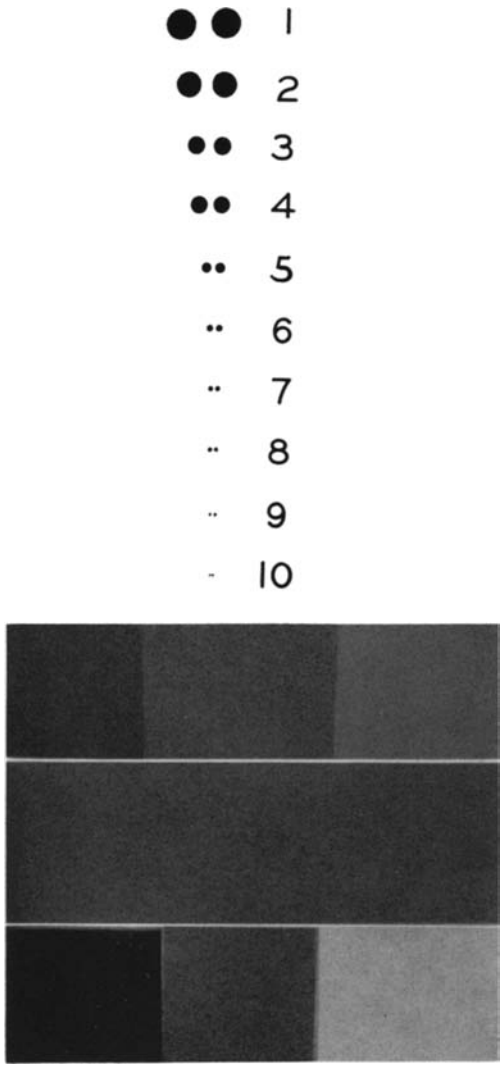

Fig. 17. Top. Doctor Henny's "Adaptometer" based upon visual acuity. As the dots decrease in size, their separations are proportionately decreased. For clinical use a positive transparency of these dots, on photographic film, is placed on top of lead glass shield of fluoroscope, there being a filter of 3 mm. Cu on table top below illuminated section of screen. Such a filter (3 mm. Cu) cuts the brightness level of the fluoroscopic screen to that which obtains during fluoroscopy of the abdomen of a heavy patient. By observing how far down the series of numbered dots he can discern separation, the fluoroscopist can measure his degree of dark adaptation in terms of visual acuity.

Bottom. The author's "Adaptometer" based upon intensity discrimination. High degrees of contrast are present in the lower row of densities while the upper row exhibits low degrees of contrast. By observing thickness of filter (wedge or stepladder) which can be introduced between fluoroscopic shutter opening and screen without rendering a given contrast (intensity difference) invisible, the fluoroscopist obtains a measure of his dark adaptation.

brighter fluoroscopic images and the great advantage to humanity which their arrival would entail. After all, it was easy for the physicist to realize that greater degrees of magnification than were possible with the optical microscope would be of extreme value to biologists and physicists. In the case of the fluoroscope it has not been so easy to outline the need, for only through such a theoretical approach as the present one could the possibility be realized.

One further point should be made about the potentialities of electron acceleration for the amplification of the fluoroscopic image. Without knowing just how great the resultant amplification will be, it is nevertheless possible to point out that it need not be wholly utilized for increasing the brightness of the fluoroscopic screen. A part could be used for decrease of the intensity of the fluoroscopic x-ray beam. In my opinion it is within the realm of possibility that very useful degrees of increase in the brightness level of the screen may be accompanied by a substantial reduction in the r per minute at the patient's skin.

However close the goal of a thousandfold increase of brightness of the fluoroscopic screen may be, and I suspect that it is closer than appears on the surface, we must nevertheless continue for the present to cope with the inherent limitations of present day fluoroscopy. While we are waiting for the arrival of something better, what is to be done about it? I would like to close in this vein.

1. In the first place, as never before the radiologist should lay aside guess work and apply himself to a more scientific appraisal of his fluoroscopic technic. Instead of carelessly neglecting the discipline of adequate dark adaptation, as some have done, or relying entirely upon the clock, as some others have done (I include myself), it would seem advisable for him to test his dark adaptation, from time to time if not on each occasion. Some years ago Doctor Newell and I had a device in our fluoroscopic room which we thought was quite satisfactory for an appraisal of the degree of dark adaptation. It was composed of

tiny samples of calcium tungstate mixed with radium, and by diminutions in the size of the blotch of fluorescent source, as well as by dilutions of the same, succeeding blotches became less and less visible to the partially adapted eye. One counted oneself as fully dark-adapted when one could see all of these blotches of faint luminosity down to the smallest and weakest. This was of course a test that depended upon the threshold intensity rather than on visual acuity or intensity discrimination. Doctor Henny has introduced me to a quite different solution to this problem and one which I feel has practical value for you. In Fig. 17 we see a photograph of a series of black dots, the diameters and separations of which descend as one follows the numbers from 1 to 10. In the order of descending size the diameters are, in millimeters, 8, 6.5, 4.5, 4.4, 2.5, 1.8, 1.3, 1.0, 0.8, 0.5. The spaces between the dots are, in the same order, 4, 2.8, 2.0, 1.5, 1.0, 0.8, 0.4, 0.4, 0.3, 0.1. You will note that the order of change of size and the order of change of spacing are not entirely consistent. The original work was done on a drawing board and the measurements I am giving you are some direct measurements on the photographic transparency which we use in the fluoroscopic room for determining the degree of dark adaptation. The technic is as follows.

The fluoroscope is operated at a routine setting that can readily be returned to. A 3 mm. copper filter is placed on the horizontal fluoroscopic table and a narrow beam of x-rays is directed through that filter onto the screen. The screen is elevated a standard distance, preferably about 12 inches, above the table top. The transparency film upon which the dots of Fig. 17 have been recorded, photographically, is placed over the small area of screen illumination and the fluoroscopist decides how many pairs of dots he can see as discrete. If under the above circumstances his eyes are well adapted he will find that the dots are separated down to and including No. 5 or No. 6, and that the remaining pairs of dots appear as though merged into single blotches. Incidentally, the level of brightness obtained through the 3 mm. copper filter with the technic as outlined is approximately equivalent to what would be obtained with 10 inches of pressdwood or about 9 inches of abdominal thickness. It is obvious that Doctor Henny's adaptometer, being based upon visual acuity, is more suited to the needs of the fluoroscopist than tests of threshold intensity.

More recently we have been experimenting with an adaptometer for the clinical fluoroscopist based upon intensity discrimination instead of upon visual acuity. Reference to Figs. 15 and 16 has suggested to us that the deterioration of intensity discrimination at low brightness levels is more important to the clinical fluoroscopist than is loss of visual acuity. At the bottom of Fig. 17 is shown a photograph of our latest adaptometer transparency, a roentgenogram of a "stepladder" of absorbent material. We have used aluminum. Ours is but a beginning and could easily be improved upon by any of you. The thicknesses of aluminum used for this present film were as follows. For the central 2 cm. $\times$ 2 cm. field an aluminum thickness of 20 mm. was used. The 2 cm. $\times$ 2 cm. square fields in the top row were exposed through 19, 20, and 21 mm., respectively. The square fields in the bottom row were exposed through 17, 20 and 23 mm., respectively. With such a stepladder transparency the procedure is as follows. The arrangement of fluoroscopic apparatus, copper filter, and adaptometer transparency is much as it was for Doctor Henny's visual acuity method. The shutters are arranged so that an area of fluoroscopic screen about 2 inches square is illuminated. The stepladder transparency is centered over this area. A "stepladder" or "wedge" of copper is interposed in the beam at the table top and the measure of adaptation is the thickness of copper at which the intensity discrimination for the smaller density steps is barely adequate. If the device should come into general use, it would doubtless be possible to mechanize it in some standardized form. As stated above,

it would be easy to improve upon this transparency and we have not yet satisfied ourselves that our approach is the best from a practical standpoint. The reason for presenting it at this time is to emphasize the importance to the fluoroscopist of the attainment of the best possible degree of intensity discrimination before considering himself as satisfactorily dark-adapted.

2. In the second place, after he has paid due attention to his dark adaptation, the radiologist should go to the pains of informing himself as to the degrees of limitation which are being imposed upon his visual apparatus at any given moment. Why should he continue to view the fluoroscopic screen and report presence or absence of certain findings without knowing just what is the measure of his disability? By means of an r-meter and Doctor Henny's figures on response of the Type B screen (Fig. 4-C), he can know fairly closely the brightness level at which he is working. After he has made the r-meter determinations with a pressdwood phantom or with a number of different thicknesses of patients, he can come fairly close to the facts merely by using a tape measure on his patient. He can then refer to such data as those of Figs. 15 and 16 in order to know how bad is his intensity discrimination or his visual acuity under the particular circumstances.

3. In the third place, in those instances where visual acuity is of prime importance and intensity discrimination of secondary concern (*e.g.*, in the case of a minute metallic foreign body) he can aid himself measurably by wearing lenses of 3 to 6 diopters, which will permit him to increase the area of retina upon which the image is focused. In other words, if he is limited to a visual acuity of 0.06 by the particular brightness level at which he is working, he will know that a separation between two contours of less than 0.24 inches will be invisible if his eye is 5 inches or more from the screen surface. By bringing his eye much closer, the discernible details can be correspondingly smaller since the retinal arc is made larger by that maneuver. In the 5-, 10-, and 25-cent stores we find satisfactory lenses for this work. I have some here in my hand which cost me 25 cents and which are definitely of value under the circumstances I have just outlined. That such lenses are not of greater usefulness in routine fluoroscopic work is due to the fact which I have tried to emphasize this evening: that loss of intensity discrimination is more important than loss of visual acuity in the average fluoroscopic procedure.

4. Some of the fluoroscopes in use today are inferior and should be modified. Target-screen distances should never be less than 18 inches and we are quite sure that 26 inches, fairly close to the maximum that is permitted by even the most convenient of tilt-tables, is an improvement over any shorter distance. Cable-connected tubes are to be preferred to other types because they permit a wider range of voltage and current variation than is usually possible with oil-immersed units.

The selection of the tube is important. In the present state of the art, none of the available tubes is above criticism. The recently developed tube of the U. S. Army Field Unit is ideally suited to the job for which it was designed, but its limitation of 100 kv.p. precludes its adoption as the final solution of our fluoroscopic x-ray tube problem. Subject to review in the light of additional knowledge and experience, we submit the following as the desirable, if not essential, features of a tube for clinical fluoroscopy.

A. It should be capable of operating at 120 kv.p. on full-wave, 4-valve-rectified transformer. B. It should be of the shockproof, cable-connected, oil-insulated type. C. It should be provided with some positive method of cooling the housing, either by air blast, as in the case of the U. S. Army Field Unit tube, or by circulating water in water jacket or cooling coils. (The forced-air-blast method gives evidence of adequacy and may make the complications of water-cooling unnecessary.) D. The anode stem should be hollow and should be provided with some method for

forcing cool oil against the copper as near as possible to the focal spot.[7]

Another feature of the average fluoroscope which needs improvement is its lack of a booster or high-energy setting to supplement the routine setting. It is extremely desirable, both from the standpoint of better fluoroscopic vision and from the standpoint of protection, that every fluoroscope should have at least two separate settings, one to be controlled by the foot switch, at an energy level which is satisfactory for prolonged observations but is preferably kept as low as feasible, the other to be at as high a level as can be permitted in view of all of the limitations, operated by a push button and so arranged that upon removal of the fluoroscopist's finger pressure the energy level returns to the lower (foot switch) value. We have added such boosters to most of our fluoroscopic beams and after several years of experience we are convinced of the importance of this arrangement.

5. Finally, it is high time that we took advantage of new knowledge concerning light adaptation and dark adaptation, knowledge that has recently been gained through the important studies of physiologists in connection with night flying. It is obvious that the effectiveness of the British night fighter pilot depends upon his being completely dark-adapted when he takes to the air to combat the Nazi scourge. The investigations which this necessity has instigated have emphasized the importance of some things which are disclosed in Fig. 12 and hinted at in Fig. 10-C. Red light at wavelengths longer than 6,700 Å. apparently does not bleach visual purple. At any rate, even high intensities of such deep red light do not cut

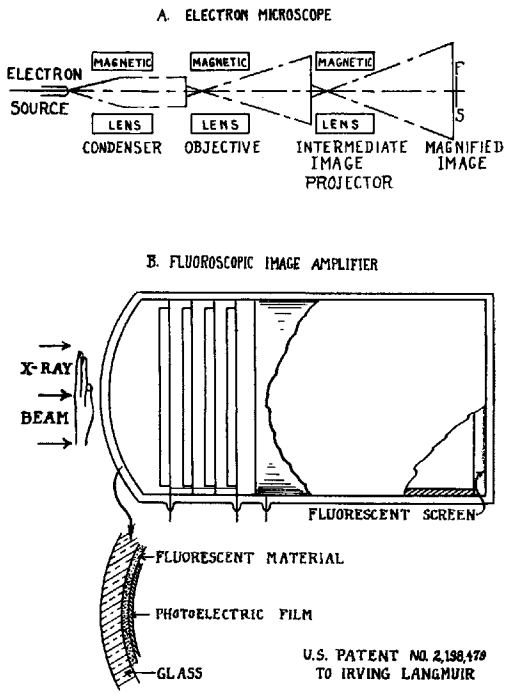

Fig. 18. Fluoroscopic screen images are technically equal in "sharpness" and "contrast" to images on x-ray films, but limitations of retinal physiology (loss of visual acuity and intensity discrimination at low brightness levels) render the available sharpness and contrast more or less invisible. From this it follows that the one great need for an improvement in clinical fluoroscopy is an increase of the brightness level of the order of 1,000-fold.

In the electron microscope the electron image possesses spectacularly good resolution even after magnification to several thousand diameters. Such magnification necessarily produces a corresponding decrease of intensity, yet reasonably high brightness levels are obtained at the fluoroscopic screen (used for field finding and focusing) of the electron microscope. This is because the available energy in the electron image is tremendously amplified by electrostatic acceleration of the electrons during their transit through the vacuum chamber. A similar maintenance of resolution, by means of magnetic lenses, is obtained in the scanning tube of a television transmitter. Ordinary light is focused upon a "photo-electric film" by the lens of the television camera. An "electron image" is thus produced and the electrons which make up this image are then accelerated by an electrostatic field.

At (B) is pictured the fluoroscopic image amplifier of Langmuir. Doubtless some such system will be successfully adapted to the problem of clinical fluoroscopy, with revolutionary effects upon the practice of medicine.

[7] Many present day tubes of the oil-insulated, cable-connected type are provided with positive circulation of the insulating oil, which conducts heat quite rapidly from the anode to the housing. The U. S. Army Field Unit tube is provided with a special motor-driven "impeller" for this purpose, but even without such a device a very effective circulation of the oil takes place through electrostatic-charge convection when the voltage applied to the terminals of the tube is rectified. (In the case of alternating potentials, connected for self-rectified operation, this electrostatic-charge convection is absent.) But the heat from the focal spot must be conducted along the anode stem before it can reach the circulating oil, and maximal power inputs, much needed if we are to take full advantage of the telefluoroscopic principle, will not be possible in the absence of some such arrangement for introducing the cooling fluid into a hollow anode stem.

down rod sensitivity. We have recently begun some work which may lead to a scientific solution of the problem of how to carry on between fluoroscopies while at the same time retaining a high degree of dark adaptation. In the meantime, a partial solution of this problem is available to anyone. You have all noticed how readily we prepare our eyes for fluoroscopy if we have been subjected to artificial light only. Even so-called "white light" from artificial sources is so weak in the more actinic rays toward the blue end of the spectrum that it partakes in minor degree of the nature of the deep red light we have been discussing. Whether or not we find a method which completely preserves rod vision, certainly we can shorten the time required for adequate dark adaptation by excluding daylight from our work rooms. At Temple University Hospital we recently began a survey of various colors of artificial illumination which are relatively beneficial to dark adaptation but are at the same time not unpleasant to work in. In these days of air-conditioning and well developed artificial ventilation, there is no difficulty in closing up windows and shielding doors so that daylight is excluded and we may decide to convert our entire department along the above lines. Preliminary tests show that a very few minutes of dark adaptation will accomplish as much as thirty or forty minutes ordinarily accomplish, if the observer has been protected from the more actinic wavelengths for a number of hours prior to entering the fluoroscopic room. It goes without saying that our researches in this direction include studies of possible colors and intensities for use on film illuminators.

In closing I need hardly point out to you that when I accepted President Wasson's assignment nearly a year ago, I did not even know enough about fluoroscopy to know that I did not know. Doubtless my ignorance is still abysmal and will appear so to me from the vantage point of another year or two. In the meantime I can honestly say that whether or not I have brought something of interest or value to you, I certainly have enjoyed the stimulation which this assignment has given me. In particular, it has renewed my enthusiasm for the physicists. Years ago we learned to rely upon them in matters of therapy and x-ray protection. More recently, physicists whose duties in therapy were not so arduous as to keep them cornered have brought us much help in the field of roentgenography. During the past year I have been a witness to another example of how helpful the physicist can be, for my own physicist, Dr. George C. Henny, has been my mentor in the work I have presented this evening. Only by reiterating this fact can I avoid the sin of taking undue credit for myself.

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