Medical Treatment by X-Rays and Other Radiation

When you are subjected to radiation, for medical purposes, the radiations are applied for one of two reasons : either that the practitioner may see through you, or that he may do work (that is, expend energy) on the surface of your body or on more deeply-seated zones. If he be employing X-rays to see through you, he may cast X-ray shadows of varying density on to a fluorescent screen so that light rays similarly varying in intensity are passed on to his eyes, and he interprets the shadows in terms of those normal or abnormal contents of your body that are casting the shadows ; or he may cause the X-ray shadows to be cast on a suitable photographic plate, where the energy of the X-rays is absorbed by the plate emulsion, so that on development he can observe the relative absorption of the X-rays by different portions of the intervened body.

You will understand that it all boils down to the energy question ; work is done to produce the X-rays, and they represent so much energy available per second. When they are played on to a body, their energy may be completely absorbed within a small fraction of an inch, they may penetrate much deeper, or they may pass right through the body with little absorbtion. We will talk about the nature of X-rays shortly, what I want you to appreciate at present is that when X-rays enter the body and do *not* pass through, so that a photographic plate on the other side is *not* appreciably affected, then the energy of the radiations is absorbed by the body, and that amount of work is done on the body in the region of absorption. Also, if a shadow is cast on a photographic plate, showing greater absorption by some material on a general line between the shadow and the target of the X-ray tube, then that represents energy missing and absorbed in the zone casting the shadow. In every case we are dealing with energy ; we want some energy to be absorbed by the body, either to do work in the zone of its absorption so as to slow down or stop the growth of unwanted cells, or so as to cast shadows on a screen or plate and indicate to us what lies in the path of the rays.

You know something of the effect of expending energy on the human body—possibly at some stage in your career you have received a punch in the eye, or have slipped in the dark and fallen so that your face struck the corner of the round table and produced results that were similar to those produced by a punch in the eye. In that case work was done by your schoolboy friend, and was absorbed by you very locally, the depth of penetration of the effect being slight. The *general* principle is the same—though this is merely an analogy.

If you happen to have served in the last great war to make the world safe for technocracy, or have resided in certain overseas cities—even in Melbourne, perhaps—you are aware of the fact that considerable energy can be imparted to small particles of matter, such as revolver or rifle bullets, which can then do work upon a body on striking it. The energy possessed by the bullets on account of their velocity is not all dissipated within a short distance, though a spent bullet might only bruise, or redden the skin. Generally, the bullet passes through, coming out with less energy than it had when it entered, the difference being the work done on the body as it tore its way through. One convenient method of regarding X-radiation is as a machine-gun barrage of bullets of energy—photons of energy we call them—which are hurled with the velocity of light on to the surface irradiated. The energy associated with different groups of these " bullets of energy " differs : in what is called " heterogeneous radiation " we have a wide range, from some of *relatively* small energy to some of relatively big energy. Those moving with lesser energy are, as you would expect, relatively easy to stop, and perhaps may only penetrate the skin ; those moving with greater energy may penetrate well within the body before they are all absorbed ; those moving with greatest energy may in many cases get right through and out on the other side. Work equivalent to the energy lost by the radiation is done on the body. There are complications due to what are called secondary radiations, but we need not worry about them here.

Imagine, for example, that I fire at you a nice fine streamlined kind of bullet, fairly light, but travelling with very high velocity, and that I fire it through some relatively unimportant portion of your anatomy, such as the fleshy part of your arm. It would whizz through neatly and come out on the other side, not having lost very much of its energy. If it struck a bone, of course, it might actually lose all its energy of movement and stay there, but I have aimed at the fleshy part, so you will not suffer that inconvenience. If I fired a round bullet instead, although it might be of the same mass and travelling with the same velocity when it hit you, there would be much greater resistance to its penetration, it would probably give up all its energy to your arm, not coming out on the other side, and doing this much more work on you, with consequently greater damage to tissue. If I fired at your arm a vast number of tiny bullets, and let those that came through penetrate a sheet of paper as target on the other side, then we could *arrange* for the energy or penetration of those tiny bullets to be such that none passed through the thickest part of bone, and most just passed through the thinnest and least fleshy part of the arm. We would then see a diagram on the sheet of paper which would be, in effect, a bullet shadow picture of the material within your arm.

In using X-rays, instead of having material bullets we fire the little packets of energy, the photons, and we can choose the energy associated with those just as we could in the case of the bullets. In the case of " hard " radiation, the photons each represent relatively big energy packets ; in " soft " radiation, the photon bullets are each of less energy. So " hard " radiation penetrates further than " soft " radiation. Heterogeneous radiation applied to you implies the bombardment of your body by a wide variety of energy bullets, ranging continuously from those of least energy to those of greatest energy. Even in that radiation there are " peaks "—that is to say, if we calculated the number of photons between different energies, we would find that we had maximum associated with certain small ranges of energies. When we use homogeneous radiation, we are working with flights of energy missiles of about the same energy each—we have cut out by some means, or have failed to produce, those of higher and lower energies than those which we wish to employ.

You will remember that the photons of least energy are most easily stopped. So that we can " filter " them out of our heterogeneous radiation by making the X-rays pass through thin sheets of aluminium, for example. We say we filter out the soft radiation. That is important, because if we wished to deliver a large quantity of energy to the body to do work on some deep-seated diseased tissue, or to pass through and effect a photographic plate as target with a " shadow picture ", the big quantity of soft radiation present might do permanent damage to the skin, causing an X-ray dermatitis. What would be the first effect on the skin, due to the work done on it? Would we see the effect?

The first *observed* change is that the skin begins to redden (this occurs some days after the dose is administered), and we have given an erythema dose, and produced an erythema. That does not produce any permanent damage, though hair may fall out and it is an indication of the dose given; but such effects, repeated too soon or frequently, might well result in permanent damage to the body cells affected. It is possible for the body to be subjected to such hard radiation that there is very little absorption within the first tenth of an inch, and then danger of production of skin diseases is minimised. The effect of radiation on all cells in the body is not the same. Quite definitely, abnormal cell growths, such as cancers, are more seriously affected by absorbing energy than are the so-called healthy, or normal cells, into which they penetrate. But the healthy cells filling their normal functions of growing by dividing and propagating themselves are affected, as you know from other examples.

Let us cast our minds back, then, to an earlier period in our lives, when at our mother's knees—or at our father's, if he was responsible for the inflicting of corporal punishment—we were subjected to blows with a flat object—the hand, hairbrush, or slipper—applied to the bare skin. This is an example of work being done upon the human body by the actual material contact with it of a material object moving with considerable velocity. The energy to do the work came from the parent responsible for imparting velocity to the slipper. He was able to control the energy expended in each blow, and thus the work done on the body at impact, by controlling the velocity given to the slipper.

What were the observed results? So far as the area bombarded was concerned, there was a rise in temperature, and a reddening of the skin. It would be possible to administer such a mild spanking that the energy absorbed at the skin was not sufficient to cause a reddening, or the spanking might be so energetic that the material subject to the energy changes might be badly injured, resulting in a breaking of the skin surface and other obvious damage.

An application of slipper just sufficient to produce a reddening would be the provision of a mild erythema dose, and the patient would be displaying an erythema, or skin reddening due to the absorbtion of energy. With X-radiation bombardment, the reddening is due to the work done at the skin by the absorption of energy from the photon bombardment, and implies cell changes. (Remember that this is an analogy, and must not be carried too far. The mechanism and *immediate effect* of the absorption of X-ray energy by cells is *not* the same as that produced on tissue by the receipt of mechanical energy.) It will be of interest now to see how that particular bombardment is produced—how we excite the X-rays and direct them on to the patient.

Those of you who know anything about your radio set know that it contains vacuum valves, included in each of which is a fine filament of wire which is heated by passing a small current through it. From the heated wire are freed large numbers of fundamental particles of electricity, the liberation being due to the fact that the wire is heated, and not primarily to the fact that an electric current is passing through it. Unless we did something more about the matter, these fundamental particles of negative electricity (negative electrons we call them) would merely hang round the heated wire. By means of another electric circuit we can pack the heated wire with vast numbers of other negative electrons, so that those hanging about outside are repelled from home, and seek some other place where there is not such an artificial superfluity of them. Forming part of the circuit that provided that superfluity in their old home is another plate of metal which is kept short of these negative electrons—we say it is positively charged. The freed electrons move along through the vacuum, gathering velocity as they go, till they crash into the positively charged plate.

That is also the principle of the modern X-ray tube ; a big vacuum tube has a little coil of wire at one end, which is heated a dull red by a low voltage circuit. It is surrounded by a lump of metal which is then packed with extra negative electrons from a high voltage circuit, and thus being made negative, is called the cathode of the tube. A target at the other side of the tube is kept deficient in negative electrons, or positively charged, and the freed electrons from the hot filament rush down the tube and crash at terrific velocity into this target, which is called the anode. When they crash into the target and are stopped, *most* of their energy is used up in heating the target, which would soon tend to become red hot itself if not kept cooled. Some of their energy, however, is dissipated as little quivers of radiation into space from the target, this radiation being the X-rays which we have been discussing earlier. The faster the electrons are moving when they crash into the target, the bigger the percentage of more energetic photons produced as X-rays. Knowing our electric conditions (the voltage difference between anode and cathode) we can calculate the velocity with which the electrons crash into the target, and from that, the energy of the most energetic photons liberated. This gives us heterogeneous radiation ; we can filter out unduly soft radiation by passing the X-rays through aluminium or copper filters ; the upper limit of photon energy is fixed by the voltages we use. For the benefit of those interested, the voltages employed range from some thirty thousand volts up to half a million volts or more, the latter being employed for the " deep " X-ray therapy of which you have probably heard.

We are accustomed to being bombarded continually by little missiles of radiant energy, photons. The sun is one big source of these, and our earth and everything exposed on its surface is irradiated right throughout the natural day by direct radiation, and often throughout the natural night by photons reflected from the moon. We call a big batch of these radiations light—though the hardest radiation reaching us from the sun does not affect our optic nerves to cause vision, nor does the softest. That is the only difference between the X-radiation and the solar radiation—one of so-called " hardness ", or energy associated with each photon.

Calling the energy associated with those photons which cause you to see red light 1, then the photons of greatest energy which cause vision have a relative energy of about 2 in each such packet. These more energetic missiles cause you to see violet, and the receipt of photons of energy between 1 and 2 gives you the varying colour effects of the spectrum. With the yet more energetic photons greater than our unit 2 received from the sun we do not associate colour effects, but they cause great chemical activity, and are very easily absorbed. Very little penetrates mist or fog, and most of them are absorbed by our atmosphere—so the higher you go, the greater the dose of these more energetic photons you receive. Calling the " soft " ones which give red colour sensations in the eye and brain 1, and the other extreme of the colour ones that give a violet impression 2, the energy associated with each photon of our softest X-radiations is some 3,500 ; they are intensely energetic little energy packets. That associated with each photon of hard X-rays is as much as 150,000. So you can get an idea of the relative penetrating ability of " light " and of X-rays. Those of relative energy slightly greater than 2 falling on our skins are absorbed in a short distance—a very small fraction of an inch—and give up their energy. They also cause an erythema, or reddening of the skin—we call it sunburn in this case. Nature frequently protects us from a bad skin disease, which may lead to skin cancers, by protecting us from excessive sunburn by introducing a pigment which prevents the more active radiation penetrating beyond a very superficial layer.

People frequently have artificially produced photons of energy slightly less than 2 on our scale irradiating them—they take ultra-violet light baths. The erythemal effect, or sun burning, is produced without the sun. Ordinary glass blocks out most of these photons, so that for sun parlours in hospitals glass is employed which does not cut out ultra-violet radiation from the sun.

I have space to refer to one other source of radiation : radioactive material. As the element radium breaks up into other elements, some of its transformation products shoot off (amongst other " things ") very energetic photons called γ-rays. Taking the energy in visual photons as being from 1 to 2, and in ordinary X-ray photons from 3,500 to 150,000, we find the energy of each photon from radium to be about 600,000. Little " seeds " of radioactive material are frequently buried in malignant growths, so that they may bombard the living cells in their immediate vicinity with these intensely energetic photons of energy, destroying the tissue round about them. There is not space to go further into the discussion, but if I have given you some idea of the relationship between these different photons (frequently called quanta) and their penetrating ability, I may have helped some of you to an understanding of a fascinating and valuable aspect of applied physics.

SYDNEY UNIVERSITY EXTENSION BOARD

Lectures and Discussions on Economics

1937

The third of the Annual Conferences will be held at the University on Monday, Tuesday and Wednesday, 6th, 7th, and 8th September. The previous meetings, held at the University during the corresponding vacations in 1935 and 1936, proved very successful; reports received from those attending showed that the lectures, and discussions arising from the lectures, were appreciated and of value not only to Teachers of Economics, but to Economists in general. It is expected that the Conference will on this occasion be equally valuable.

The subjects will be distributed over a wide range. Economists associated with banking, and bankers, who have been interested especially in the recently issued Report of the Banking Commission, will be pleased to know that **Professor R. C. Mills** is to give two lectures, and direct the discussion on **"Central Banking in Australia"; Dr. R. B. Madgwick** deals with **Population and Immigration Problems;** and **Mr. Butlin** with **Trade.**

THE PROGRAMME WILL BE AS FOLLOWS:

(Morning sessions will commence at 9.30; afternoon sessions at 2.)

MONDAY, 6th SEPTEMBER.

MORNING SESSION.—Professor R. C. Mills, LL.M., D.Sc. (Econ.): "Central Banking in Australia."

AFTERNOON SESSION.—Professor R. C. Mills: "Central Banking in Australia."

TUESDAY, 7th SEPTEMBER.

MORNING SESSION.—Dr. R. B. Madgwick, M.Ec. (Lecturer in Economic History): "The Theory of Population."

AFTERNOON SESSION.—Dr. R. B. Madgwick: "Immigration and Closer Settlement in Australia."

WEDNESDAY, 8th SEPTEMBER.

MORNING SESSION.—Mr. S. J. Butlin, B.Ec., B.A. (Assistant Lecturer in Economics): "Recent Trade Cycle Theory."

AFTERNOON SESSION.—Mr. S. J. Butlin: "Recent Trade Cycle Theory."

As on previous occasions, opportunity will be taken during the Conference for a discussion of the Syllabus and of problems arising from the teaching of economics in schools.

A charge of one guinea will be made for attendance at the Conference.

IN ORDER TO COMPLETE ARRANGEMENTS, YOU ARE ASKED TO COMMUNICATE IMMEDIATELY WITH THE EXTENSION BOARD, THE UNIVERSITY OF SYDNEY, NOTIFYING YOUR INTENTION OF BEING PRESENT.