H. F. COOK
Reader in Physics, University of London
Middlesex Hospital Medical School

Physics in the education of radiologists and medical radiobiologists

Mr. Chairman, Ladies and Gentlemen,

Before coming to the title and substance of my paper, I would like to say a few words on the question of medical physics departments organized on a University basis as compared with on a purely hospital basis. This seems to be one main problem under discussion in Italy.

I have had experience of both, and I think that under the conditions which have evolved in Great Britain, there is a place for both types of organization, with overlapping functions.

In a University-based medical physics department such as mine we aim to do two main things:

1) to provide post-graduate education and to foster research activities for physicists, medical graduates and others in some areas in bio-medical physics. We do this *in the environment of similar activities in other medical sciences.* This is mutually beneficial, and is leading to a much broader concept of what constitutes basic medical science to-day, and to revised ideas of how best to provide medical science education for medical students. In my medical school, physics takes its place in the curriculum, for example.

2) to also provide physics services, with associated applied research, to chemical departments of the hospital, with the main emphasis on radiotherapy, nuclear medicine, health physics and medical electronics. Associated with this, we provide vocational training for radiologists, radiological technicians, and to others working in the other fields specified above.

This kind of organization is appropriate to some of our teaching hospitals in the University of London, that it may not be found possible to envisage the setting-up of such departments in other countries. It leads to relatively large staff numbers (for example, 20 to 30), with the advantage of continual exchange of ideas between the members of the various groups of workers, and the stimulation this provides. Working in the same institution alongside not only clinicians, but also workers concerned with the research and teaching in other basic medical sciences, is also most beneficial for the staff of the physics department.

It must be admitted that, with these wide responsabilities, the second aim may tend to become subordinate to the first. A university environment is obviously more conducive to concentration on teaching and fundamental research, and care must be taken to see that the applications of physics in clinical medicine do not suffer.

The hospital based physics departments in Great Britain have more limited functions, and are mostly organized to concentrate on the application of physics and electronics to clinical medicine only, though this does not exclude some fundamental research work being undertaken also. The larger departments in Great Britain have been in the forefront in this aspect of bio-medical physics. Many physicists find great satisfaction in applying their knowledge in this way, rather than in pursuing more academic studies. Radiotherapy physics especially has been largely developed through the vigour shown by hospital-based physicists in tackling the problem involved in this work.

It would be wrong to my mind for any country wishing to improve the position regarding physics in medicine to decide to set up one type of department to the exclusion of the other. Both types are necessary for the proper development of physics in medicine as a whole. As long as their difference in function is recognised, there should be no problem as to whether one type of department is thought superior to the other. Both should be considered as equally important.

The two types of organization inevitably overlap in some respects, and teaching activities are found in both. The hospital-based department is well equipped to provide vocational training for radiologists and other specialists. The university department can also do this, but in addition, it has the important function of providing the more *academic* post-graduate education of physicists and others involved in medical science, cancer and biological research. Time does not allow me to discuss with you the broad picture of physics in medical education, and I have thought it appropriate only to give you details of our teaching programmes in clinical radiology and in one of the newer medical sciences, radiobiology.

I will preface these by some *short* general comment on physics in medical education at the undergraduate level.

1) Physics in medical undergraduate education

In most countries the further education in physics of medical graduates specialising in the physics-based medical specialties and sciences presents a problem the solution to which many will say has not yet been found. Much of the difficulty has arisen from the dismissal from the minds of medical students and teachers of the idea that physics has any worthwhile part to play in *undergraduate* medical education. However, medicine is rapidly becoming more scientific, curricula are being revised, and there is reason to hope that trainee radiologists and radiobiologists in the future will have found physics to occupy a more important place in their undergraduate curricula, and therefore in their minds.

Medicine has been described as an art, aspiring to the conditions of a science, as greater precision in diagnosis and treatment is sought. In this evolution towards scientific medicine, the natural science foundation on which medical education is based is of much greater importance today than ever before. The value to a medical student of a good knowledge of biology and chemistry has long been realised, but it has been much more difficult to drive home to students and the medical profession alike, that a firm grasp of physical principles and physics applied to medicine is equally, if not more, important.

In many countries it appears that the bulk of entrants to medicine has found mathematics and physics at school difficult disciplines, and they are ill-prepared to apply the concepts and principles of physics to the study of the basic medical sciences, and to understand the applications of modern and classical physics to the science and practice of medicine. It is argued that this deficiency does not affect the ability of a medical graduate to become a good general practitioner or family doctor, where the « art » of medicine is still thought to be almost the sole requirement. There is no need to have scientific doctors in this major field of employment, it is said. There has been much truth in this, but it must be remembered that students beginning to train today will face the realities of medical practice almost a decade hence. By then, even this branch of medicine will require practitioners possessing a better scientific knowledge and outlook than it has so far been possible to produce in most of those who are products of our present medical curricula.

To meet the situation arising, undergraduate medical curricula are being, or have been, revised, and in this connection, the United States of America appear to lead the way. Even here, however, it has not yet been sufficiently realised that, to train the scientific doctor of tomorrow, a greater provision should be made in the curriculum for the further study of the physical principles of the medical sciences and of the application of physics in clinical practice.

In the years ahead, a greater proportion of medical graduates will be required for the clinical specialties and for research and teaching in the medical sciences. These areas of medical activity make obvious demands for further education in natural and applied science. Postgraduate courses in applied physics are essential to any who elect to work in the several physics-based medical specialties, of which we are to discuss only radiology and radiobiology.

2) Physics in the training of radiologists

Radiology is an oustanding example of the beneficial application in medicine of a major discovery in physics. In training radiologists, questions debated over the years, which we will now examine, are:

a) Does a radiologist need a knowledge of radiological physics for him to practice his specialty?

b) If he does, what and how much should be he asked to study while training?

c) Where should instruction in physics be incorporated in his training programme?

d) How should he be examined (if at all)?

a) *Is Physics necessary?*

Whether or not a radiologist will have a physicist associated with him when he practices his specialty, there are several reasons for ensuring that he knows a good deal about the basic physics. Two main reasons are:

I) he needs to be a « safe » practitioner! He is responsible for the irradiation of humans with potentially harmful radiation and he should understand (and be able to teach his staff) the physical principles of dosimetry and protection, at the very least.

II) he needs to appreciate the workings of his apparatus — the tools of his profession — just as much as his colleagues in other medical specialties need to understand the function and construction of their equipment.

There are only few experienced radiologists (diagnostic or therapeutic) who will disagree about the need for *some* physics instruction in the training programme of new entrants to the profession. Even these few should ponder the well-known retort to the question, Why Physics? - « Why is it that a doctor, before he can practice radiology, has to deliver half a dozen babies? ». Physics is at least as important to a radiologist as the knowledge of how to deliver a baby!

No - there is little need to discuss this point further. It is when we consider *what* physics is necessary that the main argument arises.

b) *How much physics should be studied?*

For both the radiodiagnostician and the radiotherapist the need for a study of *radiation* physics and protection is accepted. The main bone of contention over the years has been in regard to how much basic electrical physics and apparatus construction should be included in the syllabus. Many experienced radiologists say « none » or « very little » when asked the question, but they have not had to teach physics to their trainees! I am firmly convinced from many years experience that the electrical and apparatus content of our present syllabus in Britain is absolutely necessary. Radiation and radiological physics cannot be understood by students without a parallel (but interwoven) study of these electrical subjects. I have experimented at times with the syllabus and have found that the students themselves would rather have *more*, rather than less, lecture time devoted to basic electrical topics and radiological apparatus.

After he has trained, how can a diagnostic radiologist judge between a good and an indifferent radiograph or fluoroscopic image without an understanding of the apparatus producing his « picture »? How can he know about his apparatus without a study of the science and technology basic to its construction and functioning? Analyse any other aspect of diagnostic or therapeutic radiology and you will find that full professional competence in most situations cannot be obtained without a good knowledge of the physics and technology of radiology.

Those of us who teach trainee radiologists know how difficult they find these technical studies, but most students, can see the need for them and can appreciate that they benefit a great deal from them. Particularly is this so in the case of trainees from the under-developed countries for whom it is really vital that they understand the working of their apparatus and can recognise faulty behaviour when it appears.

Accepting the physicists' argument, the present syllabuses in Britain have been framed after consultation between radiologists and physics teachers. In Great Britain trainees first undergo two years basic training for a Diploma (of the Royal Colleges of Surgeons and Physicians), and can then proceed to further study and training for the Fellowship of the Faculty of Radiologists. I am concerned here only with the programme for the Diploma, as followed in London. Part I of the syllabus is common to both diagnosis and therapy and deals with physics and basic technology. Therapy students then study further applied physics alongside their clinical Part II subjects, while diagnostic students similarly have some instruction in the technical aspects of the more advanced techniques of radiodiagnosis during their clinical course.

Dealing with the Part I programme first, the course at The Middlesex Hospital comprises about 60 hrs. of lectures and 50 hrs. of practical instruction. The following table shows the division of lecture time between the subjects of the syllabus. The list of experimental procedures we ask our trainees to carry out is given in the Appendix where the full lecture syllabus is also included.

SECTION A - RADIOLOGICAL APPARATUS

Subject	*No. of 1 hr. lectures*
Revision of basic d.c. electricity	6
Electrodynamics and electromagnetic induction . . . Alternating currents and circuits	8
Electronics and devices used in radiology	6
X-Ray technology	8
TOTAL	28

SECTION B - RADIATION PHYSICS AND PROTECTION

Subject	*Lectures*
Atomic and nuclear physics . . . . Nature of ionising radiations . . . . Theory of emission of ionising radiations. X-ray tube emission. Radioactive sources and emissions	8
Interaction of radiations with matter . . . . X and gamma ray absorption and transmission. Radiological aspects	6
Detection and basic dosimetry of X and gamma rays . Beam filtration and calibration	5
Introduction to principles of radiotherapy	3
Principles of radiography and fluoroscopy	6
Principles and practice of protection in radiology . .	3
TOTAL	31

The emphasis lies as much as possible on those aspects of radiological physics which we know from experience to be most useful to a radiologist. Several topics are studied to a greater depth than is apparent from the words of the syllabus. To give one example, we go as fully as time allows into all the factors involved in obtaining a « good » radiograph (or other « image ») and in extracting from it the maximum amount of information. There is a bias towards diagnostic radiological studies in our Part I programme because we teach the therapy students in their Part II course and can therefore « specialise » for them later. We would like to see more of the diagnostic students in their Part II course also, and it is lack of physics lecture time in this that forces us to concentrate on radiodiagnostic physics in the Part I programme.

Our Part II physics programme for therapy trainees is given in the next table. It consists of approximately 20 hrs. of lectures and 30 hrs. of lecture-demonstrations, and, of course, is designed to carry on from the Part I syllabus.

D.M.R.T. LECTURE PROGRAMME IN PART II PHYSICS

A) Lectures at British Institute of Radiology

Revision of radioactivity and properties of α, β and γ rays.
Specific gamma ray constant.
Radium and radon sources.

Induced radioactivity. Production, nature and properties of isotopes used clinically and in beam units.

Calculation and measurement of gamma ray exposure-rate from sources of simple geometry.

Specific feature of X-ray generators, tubes and accessories from 5 kV to 50 MV.
Gamma ray beam units.

Energy absorption, absorbed dose, exposure, etc., for X- and γ-rays. Dosemeters.

Dosimetry methods in interstitial, surface and intracavitary radium and radon therapy. Extension to other isotopes in common use.

Radiation hazards and protection in radiotherapy.

B) Lectures and Demonstrations at Medical School

Physical basis of radiotherapy using external X- and γray beams. Dose distribution and factors affecting it.
Treatment planning with fixed fields. Beam directors.

Dose distributions in moving field therapy and in Grenz-ray, contact and superficial therapy.

Physical basis of radiotherapy using particle beams.

Physical basis of the use of unsealed radioactive materials in therapy. Tracer techniques.

While discussing « how much physics », we should also mention the *standard* aimed at. This is determined by the dual limitations of study time and of the ability of medical graduates to build on their previous physics knowledge. The standard we achieve in Britain is best illustrated by reference to that of the best-known radiological physics textbooks in English. These have their variations among (and within) themselves, being either too advanced or superficial in many topics, depending on the special interests and teaching experience of the authors. But, on the whole, they give a good indication of the level of physics to which we bring our radiological trainees.

Finally, when comparing our programmes with, say, those of the United States, it should be noted that nuclear medicine (i.e.the non-therapy uses of radioisotopes in medicine) is almost entirely excluded. At the moment there is no organised or recognised training programme for doctors who wish to specialise in nuclear medicine. The best they can do is to take most of the radiotherapy physics programme and obtain other tuition in the physical aspects of nuclear medicine on a tutorial basis.

c) *When should physics be taught?*

This is another matter for argument in Great Britain. In the case of therapy trainees there is no difficulty - their physics education is a continuing process throughout their clinical training. It is for diagnostic trainees that I feel our present system can be improved. At the moment, the physics education has to be completed in the first four months of training, and during this time the trainees receive little or no instruction within the clinical X-ray department. The disadvantages of this arrangement are that the pace of the physics course is too swift, and that the students deal with the more advanced and applied physics topics without seeing at the time the practical implications of these in radiological practice.

I would prefer to see the period of physics instruction extended to from six to twelve months, and linked *from the beginning* with organised instruction, within the X-ray Department, in the use of apparatus, protection, dark room techniques, special procedures, etc. Trainees with whom I have discussed this question mostly approve of this idea.

d) *Should there be an examination?*

A student's diligence on a course is much improved if he knows there is an examination at the end! Few disagree with the idea that, for this and other reasons, radiological trainees should be examined in radiological physics. What form should it take? We in Britain use the full procedure of a written paper, practical examination and an oral examination, for both the Part I of the Diploma and for the therapy Part II.

A recent example of the Part I examination is given in the appendix. Nearly all questions are less academic than applied, and are on topics of importance in the proper appreciation of the physical aspects of radiological practice.

In the practical examination, the candidate is asked to undertake one two-hour experiment, and his oral consists of a fifteen-minute interview with two examiners, one a physicist and the other a radiologist.

3) Physics education for radiobiology

Although some radiobiology is included in radiotherapy training syllabuses in Britain, a need has arisen in recent years to provide another type of training, for both scientific and medical graduates, in radiation biology and radiation physics, mainly with a view to providing entrants to research schools and to the ever-increasing number of organisations requiring health physics personnel. It is essential that some medically-qualified persons should be recruited in these areas of activity.

The University of London (amongst others) set up in 1959 a Special Advisory Board in the joint subject of Radiation Biology and Radiation Physics, and have arranged that Schools of the University should provide two-year courses based on the Board's approved syllabus, leading to a Master's Degree. We at The Middlesex were among the first to organise such a course, on an intercollegiate basis with Guy's Hospital Medical School. Medical graduates who enter this course have even greater problems to face than have radiologists! The physics syllabus is both wider and deeper, as can be seen from the next table.

M. Sc. COURSE IN RADIATION BIOLOGY AND RADIATION PHYSICS FIRST YEAR - BASIC PHYSICS TOPICS TO BE STUDIED

Basic concepts and units. Nature of energy. Law of conservation.

The gas laws; real and ideal gases. Significance of ideal gases in heat.

Experimental methods in mechanics.

Kinetic theory; the mechanical model for the behaviour of gases and liquids. Qualitative explanation of heat transfer, viscosity, pressure.

Measurement of quantities related to kinetic theory (diffusion, viscosity). Basic experimental methods.

Heat as a mode of motion of matter. Nature of temperature. Temperature scales and the significance of the ideal gas scale.

Units of heat. Heat phenomena such as expansion, conduction, and convection.

Measurement of temperature and heat (modern experimental methods). Radiation.

Geometrical optics, basic concepts. The simple microscope.

More advanced microscopes; phase-contrast, interference, dark-field, u.v. and infra-red.

Spectra (discrete) and the structure of the atom. Molecular spectra.

Fluorescence and phosphorescence.

Photoelectricity; internal and external photoelectric effects. Photovoltaic, photoconductive, and photoemissive cells. Recent developments (solid-state amplifying devices, photomultipliers).

Structure of the atom - nucleus and electron shells. Nature of radio activity, natural and artificial.

Experimental methods in nuclear physics. The fundamental particles. Laboratory production of accelerated particles.

Elementary physics of fission. Significance of fission products in medicine. Preparation of radioisotopes.

This programme is taken in addition to those in radiological physics and premedical physics, both of which courses are attended by radiobiological students. They receive over 250 hours of formal instruction, with practical work in addition.

However one academic year of full-time work is given up to these studies, and medical graduates are able to reach the required standard in this time. They (and any other non-physicist students) take a qualifying examination in physics before proceeding to the second year.

The programme for this second year is given in the next table.

M. Sc. COURSE IN RADIATION BIOLOGY AND RADIATION PHYSICS

Summary of lecture course for 2nd year class

Subject	*No of lectures*
Molecular Biology (cytology, nucleic acids, proteins, structure and function, synthesis, biological codes) (now transferred to 1st year)	15
Genetics and Radiation Genetics	12
Human Karyotypes	1
Cellular Radiobiology (lethal effects on cells, inhibition of growth, chromosome aberrations)	7
Mammalian Radiobiology (acute radiation syndrome, effects on tissues and organs, delayed effects, carcinogenesis, effects on immune response, etc.)	12
R.B.E. and L.E.T.	3
Dose rate and dose fractionation	2
Radiation sensitizers	3
Chemical protection	2
Effects of radiation on biochemical processes	4
Restoration and recovery	2
Mechanisms of radiation action and modification . . .	3
Radiation chemistry	3
Radioactivity in food chains, etc.	4
Theory of autoradiography and histology	6
Clinical use of isotopes	2
Radiation physics (interaction of radiations with matter, particle accelerators, reactors and technology of X-ray production, preparation of radio-active substances, measurement of radiation, dosimetry)	30
The principles and practice of the Control of Radiation Hazards (shielding, safety precautions, waste disposal, maximum permissible doses, codes of practice, public health requirements)	10
TOTAL: about	120

The more advanced and applied physics is studied during this year, in conjunction with the programme in radiation biology. The M.Sc is then obtained by written examination (two 3-hr papers), a dissertation (of about 15,000 words) and an oral examination.

There is little doubt that the physics studies taken during this two-year course take medical graduates to a standard of physics higher than in any other physics-based specialty open to them. It is gratifying that, when given adequate time, they can meet the challenge, though the programme demands from them a great deal of hard work.

APPENDIX

THE MIDDLESEX HOSPITAL MEDICAL SCHOOL

D. M. R. PART I COURSE 1963-64

Lectures

The course will consist of approximately 60 lectures extending (4 per week) from:

Monday 7th October to Friday 20th December, 1963.
Wednesday 15th January to Friday 31st January, 1964.
(Examination date - 10th February, 1964).

Lectures are at 2 p.m. on Mondays, Wednesdays and Fridays and 3.15 p.m. on Wednesdays in the Lecture Theatre No. 1.

Practical sessions

There will normally be two practical sessions per week; on Mondays and Fridays from 3.0 p.m. to 5.0 p.m.

Textbooks

It should be emphasised that no single textbook adequately covers the whole course. Suggested books are as follows:

1) For very elementary introductions to electricity and X-rays:
   The Fundamentals of X-ray and Radium Physics - Selman (Charles C. Thomas)

2) Any good modern textbook of electricity of about G.C.E. Advanced Level examination standard.

3) One of the following books should be obtained as a main textbook:
   Radiological Physics - Young (Lewis) or
   Radiologic Physics - Weyl & Warren (Charles C. Thomas), or
   Radiology Physics - Robertson (Chapman & Hall)

4) Reference should also be made to sections of:
   Medical X-ray Technique - van der Plaats (Phillips)
   Modern Radiographic Technique - ed. Files (Newton Victor)
   Medical Photography - Longmore (Focal Press)

A Student's Radiological Mathematics - Kemp (Blackwell)

Recommendations of the International Commission on Radiological Protection (Pergamon)

Code of Practice for the Protection of Persons exposed to Ionising Radiations (H.M.S.O., 8/-).

D.M.R.T. Only

The following books are recommended for « Physics as applied to Radiotherapy » in Part II of the D.M.R.T. course, *Sections of some of them are suitable also for parts of the Part I course.*

The Physics of Radiology - H.E. Johns (Charles C. Thomas)

Physical Foundations of Radiology - Glasser, Quimby, Taylor and weatherwax (Hamish Hamilton)

Radium Therapy - Its Physical Aspects & Extension with Radioactive Isotopes - C.W. Wilson (Balliere, Tyndall & Cox).

For reference purposes:

Artificial Radioisotope Therapy - Hahn (Academic Press)
British Journal of Radiology - Supplement No. 2. Mayncord
Handbooks 78 and 84, National Bureau of Standards.

MIDDLESEX HOSPITAL MEDICAL SCHOOL

D.M.R. Part. I - Detailed Syllabus in Physics and Radiological Apparatus

Lecture Programme

The course is covered in approximately 60 lectures. After subjects, A1, A2, A3 and half A4 have been completed, instruction in the subjects under section B is commenced, and continued in parallel with Section A until the end of the course.

A) Electricity and Radiological Apparatus

1) *Fundamentals and introduction to current electricity*

Electron conduction, energy conversion and electromotive force, potential difference, resistance and Ohm's Law, units. Simple circuits and their analysis.

Factors determining resistance of conductors.
Energy and power relations. Some simple methods of measurement of resistance, p.d. and current.
Electrolysis and chemical sources of E.M.F.

2) *Electrostatics*

Law relating to « point » charges. Unit charge, field strength, flux density, p.d. in a field.

Potential and energy of a charged body. Effect of dielectric medium.

Dielectric strength.

Capacitance, definition and units. C of simple bodies. Condensers and formulae for capacity.

Types used in radiology. C in series and parallel.

Effect of a condenser in a D.C. resistive circuit.

Growth and decay laws.

3) *Magnetism and Magnetic fields of Currents*

Elementary ideas of magnetic force due to electronic motion. Atomic magnetism. Ferromagnetism, poles, law of force, unit pole, permeability. Magnetic field, lines, strength, flux density. Magnetisation cycle, hysteresis. Fields round currents in conductors of various geometry. Field strength at centre of circular current, e.m.u. of current.

4) *Electromagnetic phenomena*

Electrodynamic force and laws. Principles of D.C. electric motor. Moving iron meter. Conversion of meters with shunts and resistors. Electromagnetic induction. Mutual and self inductance, definitions and unit of measurement. Effect of self inductance in a D.C. resistive circuit. Principles of generators of A.C. The dynamo.

5) *Alternating Currents*

Features of sinusoidal alternating E.M.F. and current. Specification of A.C. Phase difference between alternating quantities. Simple vector representation.

A.C. in resistive circuit. Effective heating value (R.M.S. value). Phase and magnitude relationships between voltage and current for A.C. in circuits with inductance and capacitance.

Power in A.C. Circuits.

The A.C. choke coil and applications.

Principles of the A.C. transformer with secondary off and on load. Energy losses, regulation and efficiency. The autotransformer.

A.C. measuring instruments.

Elementary introduction to three-phase A.C.

6) *Elementary Electronics, and some electronic devices used in Radiology.*

Thermionic emission. Work function. The diode and its characteristics. Types of emitter used in practice. Electrical design and characteristics of L.T. and H.T. diode rectifiers and diode X-ray tubes.

The triode. Characteristics and constants.

Dynamic characteristic. Triode amplifier. Triode as a switch valve.

H.T. triode.

Cold cathode gas diode, triode, dekatron.

Thermionic gas diode and triode.

Selenium rectifiers for L.T. and H.T.

The cathode ray tube and oscilloscope.

Photoelectricity, cells and multipliers.

7) *X-ray Technology*

Basic circuitry of a simple X-ray set.

Construction of H.T. transformer. Rating. Filament transformers.

H.T. condensers. H.T. cables.

H.T. circuits: self-rectified, primary suppressed, half-wave circuit, full-wave rectified circuit, (three and six-phase circuits with selenium rectifiers, constant voltage triode-controlled circuit- brief and elementary description only). Voltage doubling circuits for therapy sets.

L.T. control circuits: Control of H.T.: line voltage compensation, calibration of autotransformer or primary voltmeter in tube voltage.

Magnetic switch (and link with timer).

Mains resistance compensator for ward sets.

Valve filament control methods.

Tube filament control circuit. Stabilizer, space charge compensator, tube current selector.

Tube current indication.

Principles of common types of exposure time.

X-ray tubes: Factors affecting choice of material and design of filament and anode of an X-ray tube.

Radiographic tubes, 250 kV therapy tube. Rating of a tube and factors determining it. Cooling methods. Tube shield design. Care of tube.

Methods of measurement of tube voltage. Pin-hole photography of target. Detection of common faults in X-ray set working. Use of cathode ray oscillograph to monitor L.T. and H.T. circuits.

B) Radiation and Radiological Physics. Radiological Protection

1) *Fundamentals*

Atomic structure. The nucleus, orbital electrons.

Atomic number and mass number.

Nuclides, isotopes. Electron orbits and energy levels.

Excitation and ionisation.

Wave motion in matter. Electromagnetic waves.

Classification by name. Energy transfer from source to receiver.

Methods of emission. Quantum nature of light and X-rays. Intensity and quality.

Radiation spectra. Inverse square law.

2) *X-ray production theory*

Continuous spectrum. Characteristic spectra.
Factors determining the spectrum.

3) *X-ray interaction with matter*

Decrease in intensity of a divergent beam due to the inverse square law and interaction processes.

Exponential law for attenuation of non-divergent homogeneuos beam. Linear attenuation coefficient.

Half-and tenth-value-layers. Mass, atomic and electronic attenuation coefficients. Transmission of a heterogeneous beam through matter. Process of interaction. Photoelectric effect, Compton effect, pair production. Attenuation and absorption coefficient for each process. Dependence of these on quantum energy and composition of the absorber.

Data for water and lead. Spatial distribution of scatter. Practical aspects of absorption and scatter in radiology and protection.

4) *X-ray effects, Detection and measurement*

Effects of X-ray interaction. Secondary electron emission. Ionisation and excitation. Energy absorption. Elementary account of biological, photographic and fluorescent effects. Ionisation of gases.

Measurement of intensity at a point in a beam by calorimetric method. Requirement to determine the energy absorption per unit mass in matter irradiated by X-rays. The rad. Possibility of use of calorimetry to measure absorbed dose. Concept of exposure.

The roentgen and its realisation. Reasons for use of air ionisation as method of practical dosimetry. Cavity ionisation chamber. Air equivalent wall. Principles of simple dosemeters. Measurement of dose-rate at a point in a beam.

Photographic dosimetry. Limitations.

Specification of beam quality. Spectral analysis.

H.V.L., effective quantum energy.

Factors affecting intensity and quality at a point in an X-ray beam.

Principles of beam filters.

5) *Radioactivity*

Nuclear structure and stability. Binding energy. Alpha decay. Beta decay. Gamma-ray emission.

Decay and transformation laws. Half-life period, tenth-life period, mean life.

Source activity and unit of measurement.

Properties of alpha, beta and gamma-rays.

Detection of these radiations. Ionisation chamber, geiger counter, scintillation counter, film.

Naturally-occurring radioactive substances. The radium family. Radium appliances.

Induced radioactivity. Nuclear reactor.

Some commonly-used man-made nuclides.

6) *Radiological Physics and Protection*

Brief account of use of radium and other radioactive sources in therapy.

Use of gamma-rays in radiography.

Principles of X and gamma-ray beam therapy.

Beam calibration, dose distribution, factors affecting depth dose.

Principles of radiography and fluoroscopy.

Shadow formation, penumbra. Properties of films and screens.

Factors affecting the quality of a radiograph. Physical and physiological factors in fluoroscopy.

Radiation hazards. Permissible doses. Principles of protection. Protection of tubes and X-ray rooms. Shielding materials. Monitoring methods for department and staff. Protection of patients.

Methods of reducing dose in radiography.

Practical Work

About 20 experiments are undertaken in support of the above lecture programme.

Experiment 1 - Ohm's Law in D.C. circuits.

Experiment 2 - The use of the Wheatstone bridge to determine the resistivity and the temperature coefficient of resistance.

Experiment 3 - The heating effect of an electric current.

Experiment 4 - The regulation of a transformer and the action of an autotransformer.

Experiment 5 - The diode and triode valve.

Experiment 6 - X-ray high tension circuits and the use of the cathode ray oscilloscope.

Experiment 7 - Discharge of a condenser through a resistance and its application to timer circuits.

Experiment 8 - The determination of the size and position of the target of an X-ray tube using a pinhole method.

Experiment 9 - Measurement of X-ray output in air and its dependence on kV, mA and distance.

Experiment 10 - Measurement of the quality of an X-ray beam.

Experiment 11 - The measurement of the transmission of cobalt gamma rays in lead.

Experiment 12 - The measurement of skin dose, back scatter factor, and depth dose and the effect of filtration on patient dose.

Experiment 13 - The determination of the characteristic curve of an X-ray film emulsion.

Experiment 14 - The speed factor of an intensifying screen.

Experiment 15 - The improvement of the contrast of an X-ray film by the use of a Potter bucky diaphragm or stationary grid.

Experiment 16 - To determine the accuracy of a timer using a spinning top.

Experiment 17 - The localisation of a foreign body.

Experiment 18 - The determination of the characteristic curve of a Geiger counter, the measurement of the half life of Tl^{204} and the absorption of β rays in aluminium.

Experiment 19 - The use of a scintillation counter to determine the activity of a radioactive sample.

Experiment 20 - A radiation survey around an X-ray tube head. The measurement of contamination from unsealed radioactive materials.

Experiment 21 - The determination of the lead-equivalent of a lead-rubber apron and the inspection of a lead-rubber glove.

DIPLOMA IN MEDICAL RADIO-DIAGNOSIS
DIPLOMA IN MEDICAL RADIOTHERAPY

Part I

July, 1 1963

9.30 a.m. to 12.30 p.m.

Candidates are required to answer SIX questions in all, three from Section A and three from Section B - and will be expected to satisfy the Examiners in both sections.

Answers to the questions in each section must be written in the books marked « A » and « B » respectively.

Candidates are informed that one of the Examiners is present during part of the time allowed for the paper, for consultation in case any question should not appear clear.

Section A

1) Describe and explain the spectrum of radiation produced at the tungsten target of an X-ray tube working at 100 kV.

   Discuss the changes in X-ray intensity and quality resulting from changes of tube voltage, tube current and filtration.

2) Describe and discuss the physical factors which influence the transmission of X-rays through a patient.

   For the shortest wavelength in an X-ray beam the half-value-thickness of soft tissues is 4 cm, while for the effective wavelength of the beam it is 2 cm. By a graphical or any other method, determine the percentage of radiation at each of these wavelengths transmitted by 14 cm of soft tissue.

3) Distinguish between exposure and absorbed doses, and define the units in which they are specified.

   Describe the principles of a dosemeter suitable for measuring the dose-rate at points in an X-ray beam.

4) Explain the term back E.M.F., and discuss its relevance to the derivation of the off-load transformation ratio of an A.C. transformer.

   Draw a simple circuit diagram showing how an autotransformer may be used to control the output of a high tension transformer. Describe how the value of the high tension applied to an X-ray tube can be measured.

5) Summarise the properties of free electrons as used in electronic devices. Give accounts of any two electronic devices (other than X-ray tubes) in common use in radiological apparatus.

Section B

6) Either (a) Describe and explain the construction of a rotating-anode diagnostic X-ray tube. Describe how you would investigate (1) the size and shape of its focal spot, (2) whether the X-ray field in the plane of the film is uniform.

Or (b) Describe and explain the construction of a conventional (250-300 kV) therapy X-ray tube. Draw a diagram of a high tension circuit which can deliver a smoothed voltage to the tube and explain the functions of the principal components. How would you investigate the variation of dose across an X-ray field on the skin of a patient?

7) Give a brief account of the simpler phenomena of radioactivity. Explain the meaning of the terms atomic number, mass number, half-life-period of a radioactive substance.

What is the minimum quantity of a radioactive isotope of half-life 8 days which must be ordered if a dose of 50 millicuries is to be given to a patient 24 hours after it is despatched from the source of supply?

8) Describe the physical processes involved in the scattering of X-ray of γ-ray beams, and show how these processes depend on the wavelength of the radiations.

Explain either (a) how the deleterious effects of scattering can be minimised in diagnostic radiology; or (b) how scattering affects the distribution of dose in a therapeutic treatment.

9) Give an account of one of the following:

a) Apparatus for, and advantages of, megavoltage therapy.

b) Fluorescence and its use in intensifying screens and for fluoroscopy.

c) Radiation protection with respect to radiation machines and working rooms.

d) The types of X-ray films commercially available, and their relative merits.

10) Explain the necessity for and describe the methods used in the filtration of X-ray beams, either in diagnostic or in therapeutic procedures.

Explain how radiation detectors (such as are used for personnel monitoring) can be made to indicate the quality as well as the quantity of radiation received by them.

MIDDLESEX HOSPITAL MEDICAL SCHOOL

M. Sc. IN RADIATION BIOLOGY AND RADIATION PHYSICS

Information for prospective candidates

1) The course will be run jointly by the Departments of Physics and of Biology of the School. It will be a full-time course.
2) During their first year candidates will be expected to prepare for the qualifying examination by studying *either* physics or biology to a level which will make their advanced work in the second year possible. However, even in the first year some joint work will be arranged.
3) Candidates will be given formal instruction and practical exercises under supervision, but will be expected to undertake a considerable and increasing amount of independent work as the course proceeds.
4) Applicants whose qualifications fulfil the University requirements may be called for interview at the Medical School. Candidates who are accepted may wish to apply for maintenance grants from the Department of Scientific and Industrial Research or other public bodies. Such applications will be supported by the School.
5) The fees for the course will be £30 per term, payable at the beginning of each term.

UNIVERSITY OF LONDON

M. Sc. DEGREE IN RADIATION BIOLOGY AND RADIATION PHYSICS

1) Every candidate for the M. Sc. Degree in Radiation Biology and Radiation Physics is required to attend an approved course of study therefor as an Internal Student.
2) As a general rule candidates should have obtained one of the following degrees:
   a) B. Sc. (Special) Degree with First or Second Class Honours in one of the following subjects:
      Physics, Anatomy, Biochemistry, Botany, Chemistry, Mathematics, Physiology, Statistics, Zoology.
   b) B. Sc. (General) Degree under former Regulations, with First or Second Class Honours, including at least one of the subjects listed under (a).
   c) B. Sc. (General) Degree, with First or Second Class Honours, including at least one of the subjects listed under (a) taken at Part II of the examination.

d) M.B., B.S. Degrees.

e) B. Pharm. Degree with First or Second Class Honours.

f) B. Vet. Med. Degree.

3) Applications from graduates of this University who do not fulfil these conditions will be considered on their merits.

4) Applications will be considered under special circumstances from candidates holding a Licence entitling them to registration by the General Medical Council, provided that they have obtained by examination a recognised higher medical qualification e.g. the membership of one of the Royal Colleges of Physicians or Fellowship of one of the Royal Colleges of Surgeons.

5) Graduates of other Universities will be required to produce evidence satisfactory to the University of having attained a standard equal to that demanded of graduates of this University.

6) Before admission to the M. Sc. Examination all candidates, unless exempted as under para. 7 below, will be required to pass a qualifying examination. The qualifying examination will normally be taken after a full-time course of study extending over not less than one year and must be passed one academic year before the candidate enters the M. Sc. Examination. It will consist of *two* written papers of three hours each. One paper will be on Section (a) and one on Section (b) of the Syllabus. The Examiners will be at liberty to test any candidate by means of oral questions. The course of study for the M. Sc. Examination will include Radiation Physics, Chemistry and Biochemistry, Radiation Biology, Medical and Industrial applications of Radiations and the Principles and Practice of the Control of Radiation Hazards. The examination will be taken after one further year of full-time study and will consist of *two* written papers of three hours each, an oral examination and a dissertation.

7) Candidates with appropriate qualifications may apply for exemption from the qualifying course and examination for Section (a) and/or for Section (b) except that candidates other than Internal graduates in the Faculty of Science of this University, must in all cases pursue a course of study extending over not less than *two academic years* for the award of the M. Sc. Degree (see p. 1453, para. 10).

SYLLABUS

Qualifying Examination

a) *Physics.* Basic physics - introductory to atomic physics. Radioactivity and nuclear physics. Properties of radiations.
Relevant statistical methods.

b) *Biology.* Introduction to basic principles of biology relevant to radiobiology. Selected aspects of animal and plant physiology and ecology. Metabolism and food chains (including those in the sea). Elements of cell physiology, cytology and genetic. Relevant statistical methods.

M. Sc. Degree

a) *Radiation Physics.* Interaction of radiations with matter.
Particle accelerators, reactors and technology of X-ray production.
Preparation of radioactive substances.
Measurement of radiation. Dosimetry.

b) *Chemistry and Biochemistry.* Properties of macromolecular substances. Radiation Chemistry. Chemical and Biological effects of radiations.

c) *Radiobiology.* Somatic and genetic effects of radiations in cells, tissues, whole organisms (including mas) and populations.

d) *Medical and Industrial Applications of Radiations.* Use of radioactive isotopes and radiations in medical research, diagnosis and therapy; and in agriculture, chemistry and industry.

e) *The Principles and Practice of the Control of Radiation Hazards.* Radiation shielding. Safety precautions in practical uses of radiations and in the handling of radioactive materials. Waste disposal. Maximum permissible levels. Codes of Practice. Public health requirements.

INTERVENTI SULLA RELAZIONE

G. MELDOLESI

Ho ascoltato con vivo interesse le belle relazioni dei Colleghi inglesi che ci hanno esposto con grande precisione le condizioni di inserimento del fisico in campo medico nel loro grande Paese. Altri prima di me hanno illustrato le attuali condizioni dell'Italia, in questo senso. Devo però aggiungere che i pochi fisici che lavorano nei nostri Istituti di Radiologia — universitari e ospedalieri — sono da noi radiologi giustamente apprezzati e considerati.

La relazione del prof. Cook mi dà modo di precisare che se oggi, nella maggior parte dei casi, i radiologi italiani devono cavarsela da soli a eseguire le necessarie misurazioni, a costruire a usare le curve di isodosi, a occuparsi dei problemi di protezione, è pur vero che, per legge, è inibito di praticare la radioterapia a coloro che non abbiano seguito un regolare corso di specializzazione e superato i relativi esami.

La Scuola di specializzazione in radiologia che dirigo da parecchi anni ha durata triennale: e in essa il corso di fisica è biennale. Da ciò si deduca quanto siano curate le nozioni di fisica da impartire ai nostri specializzandi. Recentemente però il Collegio dei professori universitari in radiologia ha ritenuto opportuno di proporre che la durata delle suddette scuole di specializzazione sia portata a quattro anni. E' bene però aggiungere che esse abilitano all'esercizio sia della diagnostica che della terapia; perché noi siamo fermamente convinti che non si possa correttamente praticare della roentgenterapia senza avere solide basi di radiodiagnostica.