Radiation / Radioactivity / Radioactive Decay

Radioactive Particles / Counting

History – Discovery of X-rays / Radioactivity /

Nuclear atom

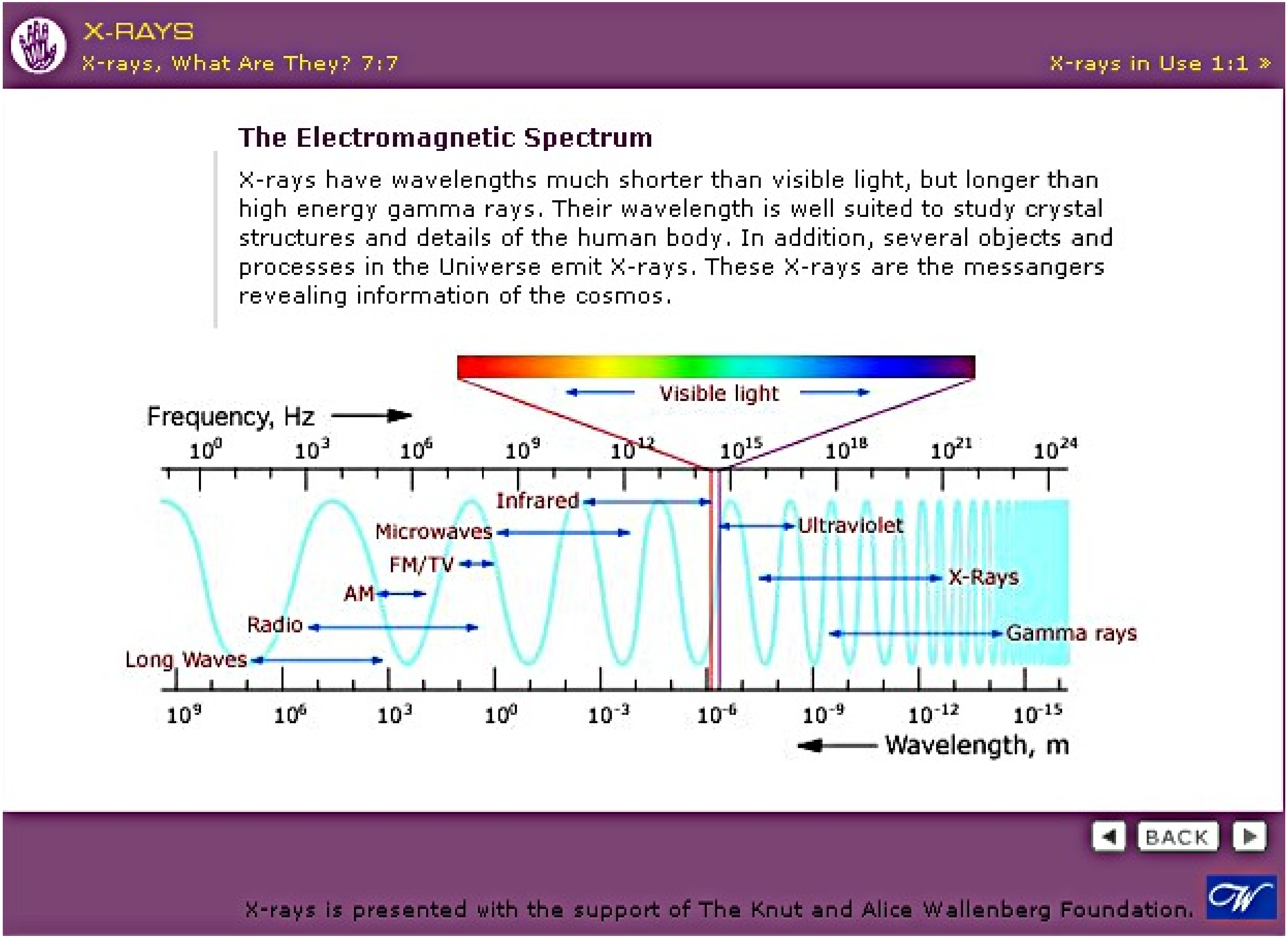
Radioactive Decay – particles, half-life and equations

Common Biological Isotopes

Terms: Radioactivity / Exposure / Dose

Counting: Film / Geiger Counter / LSC / PI

Hackert – CH370



X-RAYS

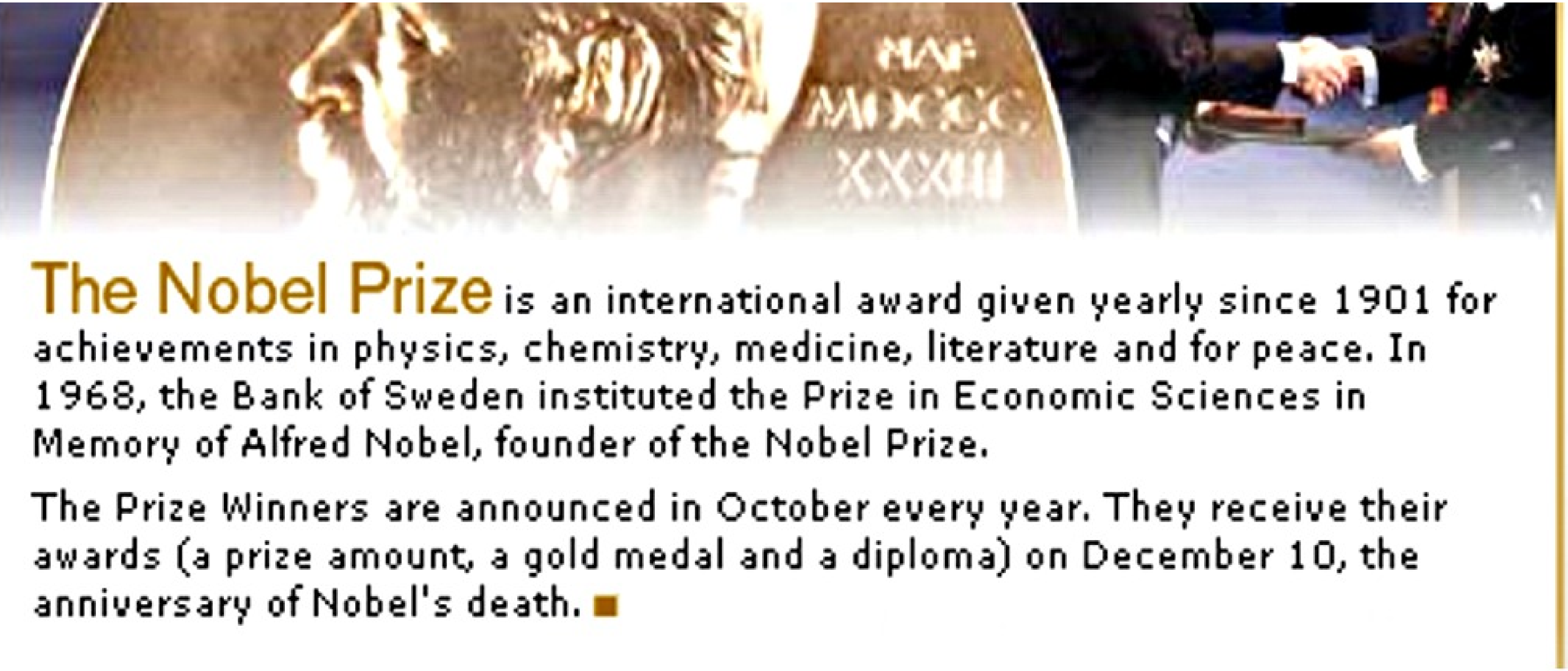
X-rays, What Are They? 7:7

X-rays in Use 1:1 »

The Electromagnetic Spectrum

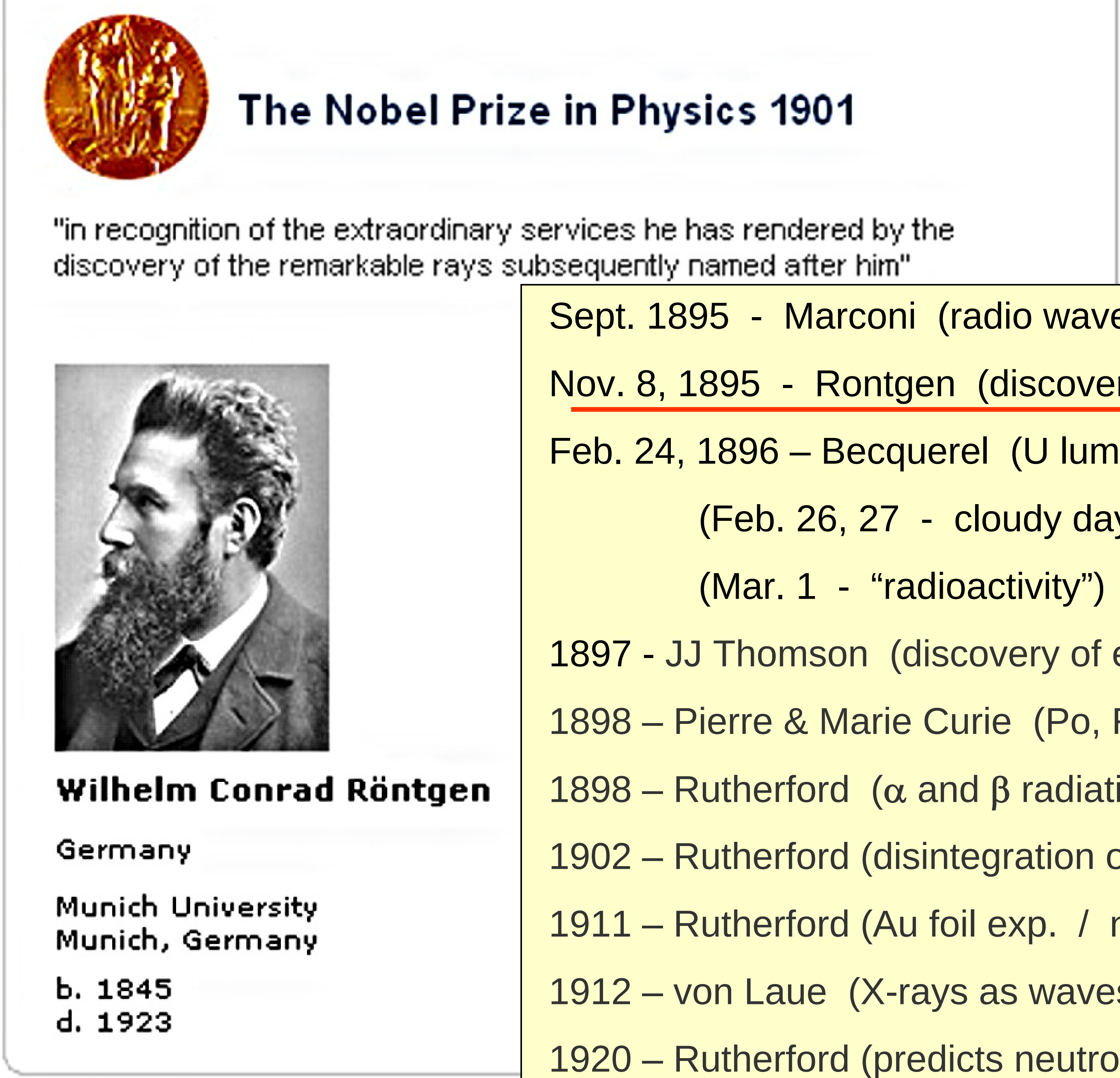
X-rays have wavelengths much shorter than visible light, but longer than high energy gamma rays. Their wavelength is well suited to study crystal structures and details of the human body. In addition, several objects and processes in the Universe emit X-rays. These X-rays are the messangers revealing information of the cosmos.

X-rays is presented with the support of The Knut and Alice Wallenberg Foundation.



The Nobel Prize is an international award given yearly since 1901 for achievements in physics, chemistry, medicine, literature and for peace. In 1968, the Bank of Sweden instituted the Prize in Economic Sciences in Memory of Alfred Nobel, founder of the Nobel Prize.

The Prize Winners are announced in October every year. They receive their awards (a prize amount, a gold medal and a diploma) on December 10, the anniversary of Nobel's death. ■



The Nobel Prize in Physics 1901

"in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him"

Wilhelm Conrad Röntgen

Germany

Munich University
Munich, Germany

b. 1845
d. 1923

Sept. 1895 - Marconi (radio waves / wireless)

Nov. 8, 1895 - Rontgen (discovery of X-rays)

Feb. 24, 1896 – Becquerel (U luminesce”)

(Feb. 26, 27 - cloudy days)

(Mar. 1 - “radioactivity”)

1897 - JJ Thomson (discovery of electrons)

1898 – Pierre & Marie Curie (Po, Ra)

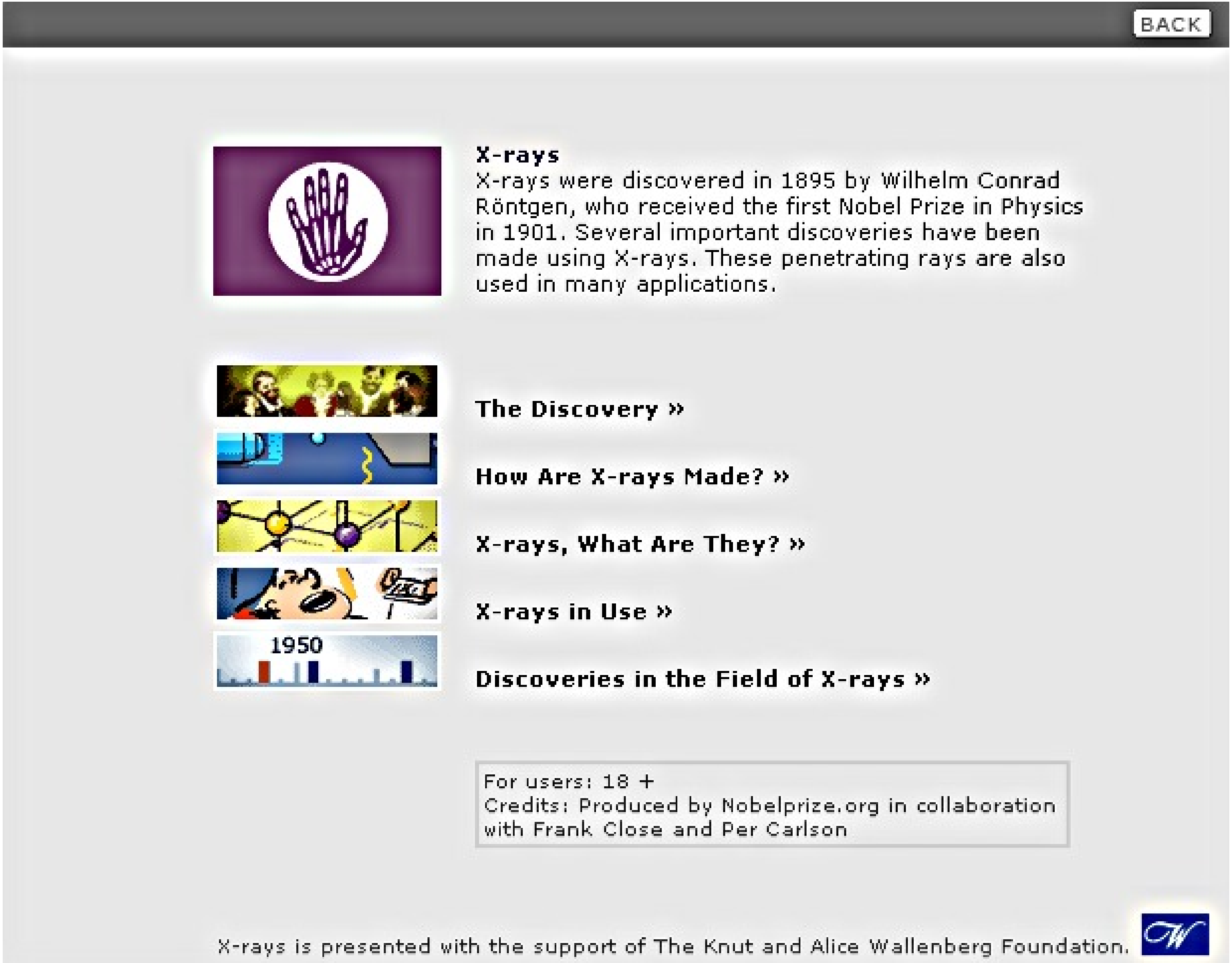
1898 – Rutherford (α and β radiation)

1902 – Rutherford (disintegration of elements)

1911 – Rutherford (Au foil exp. / nuclear atom)

1912 – von Laue (X-rays as waves)

1920 – Rutherford (predicts neutron)



X-rays

X-rays were discovered in 1895 by Wilhelm Conrad Röntgen, who received the first Nobel Prize in Physics in 1901. Several important discoveries have been made using X-rays. These penetrating rays are also used in many applications.

The Discovery »

How Are X-rays Made? »

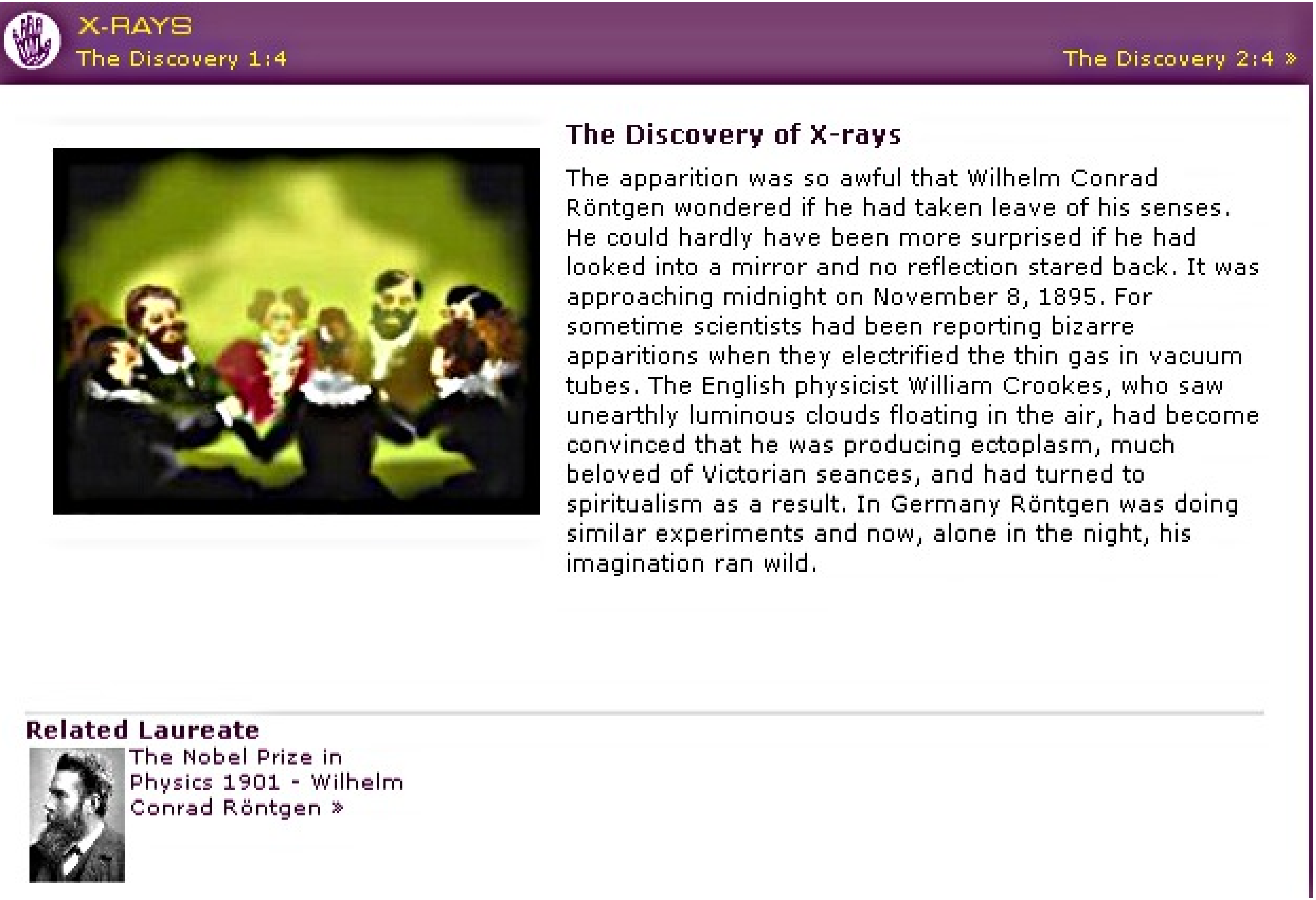
X-rays, What Are They? »

X-rays in Use »

Discoveries in the Field of X-rays »

For users: 18 +
Credits: Produced by Nobelprize.org in collaboration with Frank Close and Per Carlson

X-rays is presented with the support of The Knut and Alice Wallenberg Foundation.



X-RAYS

The Discovery 1:4

The Discovery 2:4 »

The Discovery of X-rays

The apparition was so awful that Wilhelm Conrad Röntgen wondered if he had taken leave of his senses. He could hardly have been more surprised if he had looked into a mirror and no reflection stared back. It was approaching midnight on November 8, 1895. For sometime scientists had been reporting bizarre apparitions when they electrified the thin gas in vacuum tubes. The English physicist William Crookes, who saw unearthly luminous clouds floating in the air, had become convinced that he was producing ectoplasm, much beloved of Victorian seances, and had turned to spiritualism as a result. In Germany Röntgen was doing similar experiments and now, alone in the night, his imagination ran wild.

Related Laureate

The Nobel Prize in Physics 1901 - Wilhelm Conrad Röntgen »

X-RAYS

The Discovery 2:4

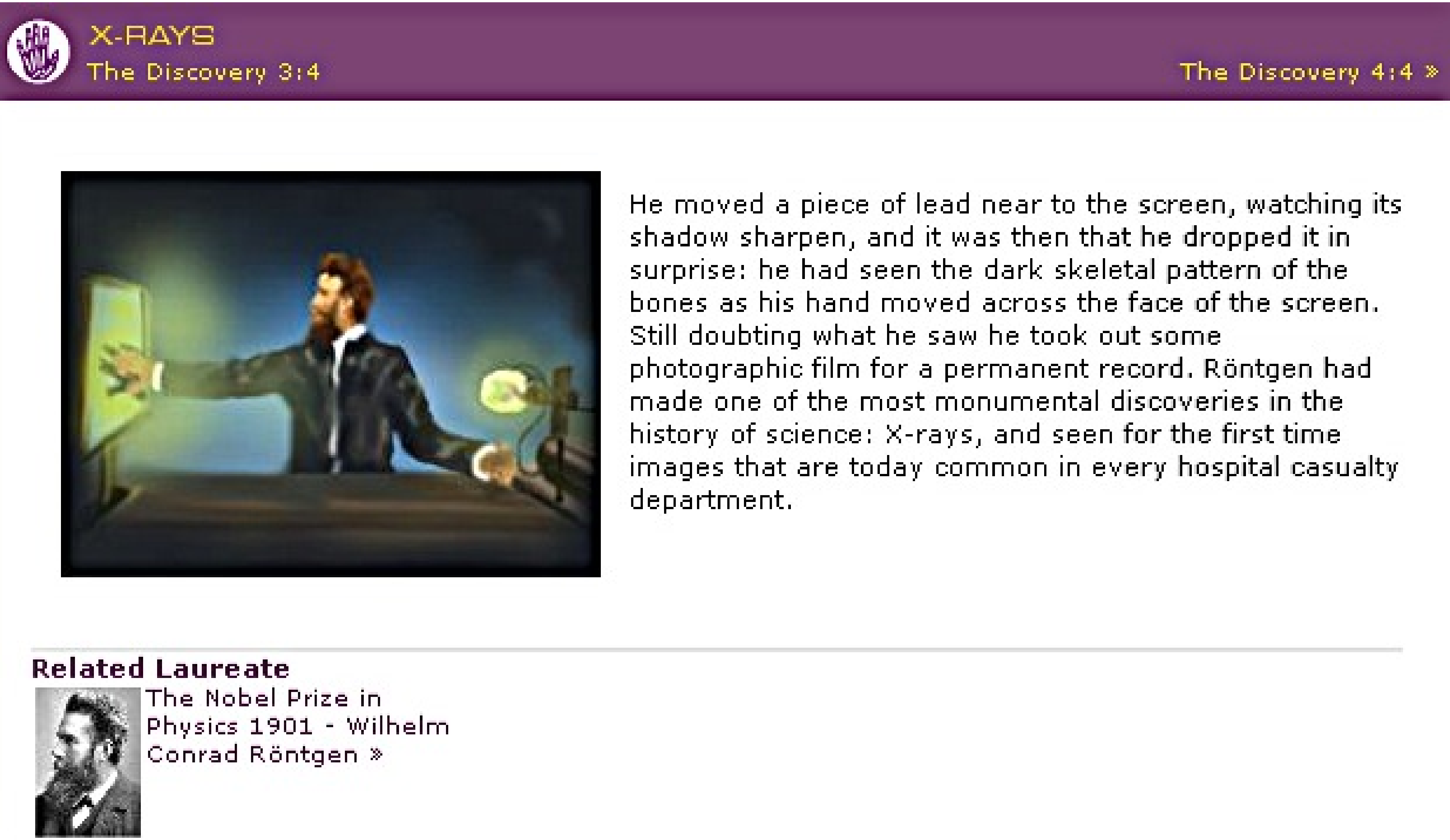
The Discovery 3:4 »

Somehow Röntgen's electrical device was producing rays that seemed to be impervious to matter, but at last he found something to stop them: lead left a shadow proving that the mystery rays were definitely real.

Earlier that day, as the November dusk darkened the laboratory, he had noticed that whenever he made sparks in the tube, a fluorescent screen at the other end of the laboratory table glowed slightly. This was the signal that he had been looking for, the sign that invisible rays were being produced in the spark tube, crossing the room and striking the screen, producing the faint glimmer. To track the rays he had been putting pieces of card in their way, but the screen continued to glow whether the cards were there or not as if the rays were able to pass clean through them. He then tried to block the rays with metal but thin pieces of copper and aluminium were as transparent as the card had been.

Related Laureate

The Nobel Prize in Physics 1901 - Wilhelm Conrad Röntgen »



X-RAYS

The Discovery 3:4

The Discovery 4:4 »

He moved a piece of lead near to the screen, watching its shadow sharpen, and it was then that he dropped it in surprise: he had seen the dark skeletal pattern of the bones as his hand moved across the face of the screen. Still doubting what he saw he took out some photographic film for a permanent record. Röntgen had made one of the most monumental discoveries in the history of science: X-rays, and seen for the first time images that are today common in every hospital casualty department.

Related Laureate

The Nobel Prize in Physics 1901 - Wilhelm Conrad Röntgen »

X-RAYS

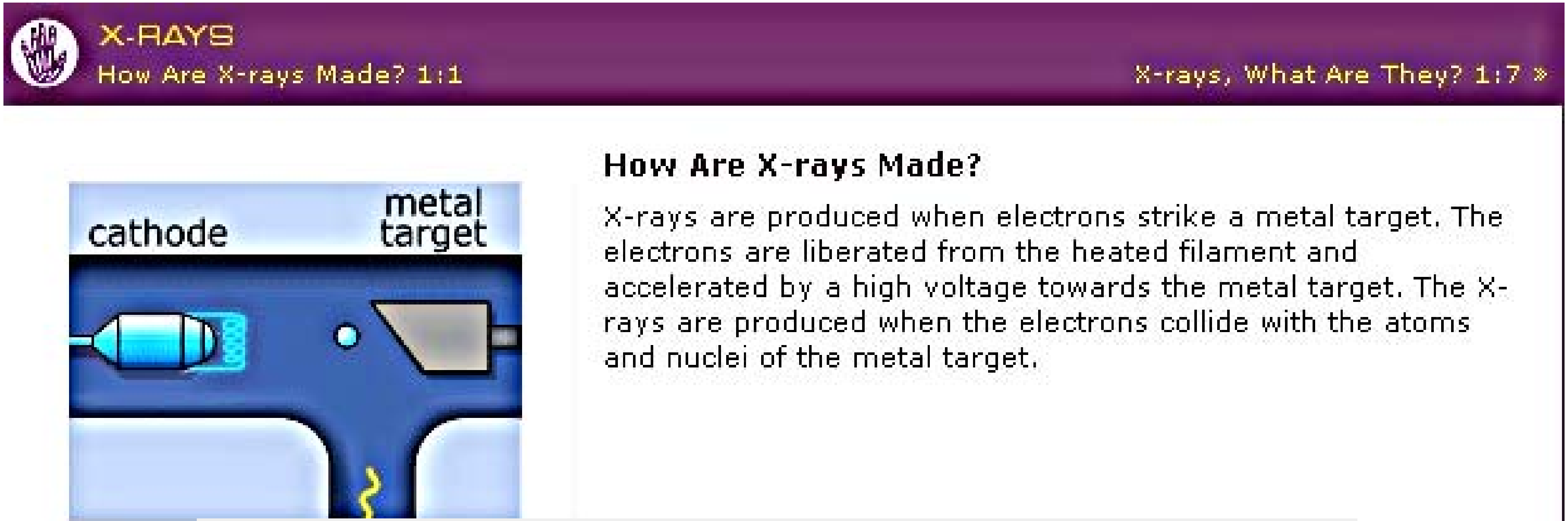
The Discovery 4:4

How Are X-rays Made? 1:1 »

Six weeks later, on the Sunday before Christmas 1895, he invited his wife Bertha into the laboratory and took a shadow-graph of the bones of her hand with her wedding ring clearly visible. This is one of the most famous images in photographic history and propelled him within two more weeks into an international celebrity. The medical implications were immediately realised and the first images of fractured bones were being made by January 1896 even though none yet knew what the mystery rays were.

Related Laureate

The Nobel Prize in Physics 1901 - Wilhelm Conrad Röntgen »



X-RAYS

How Are X-rays Made? 1:1

X-rays, What Are They? 1:7 »

How Are X-rays Made?

X-rays are produced when electrons strike a metal target. The electrons are liberated from the heated filament and accelerated by a high voltage towards the metal target. The X-rays are produced when the electrons collide with the atoms and nuclei of the metal target.

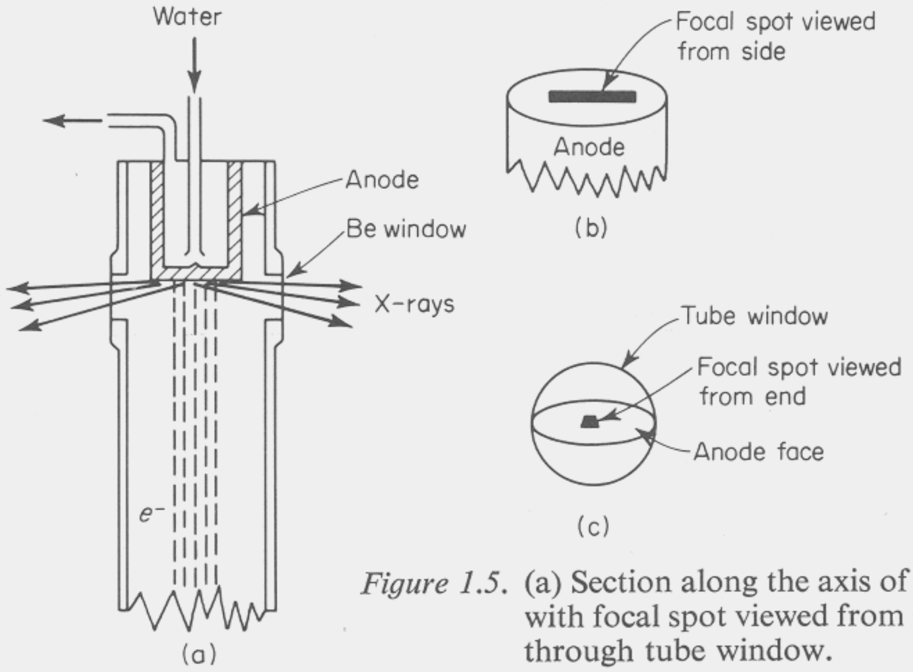
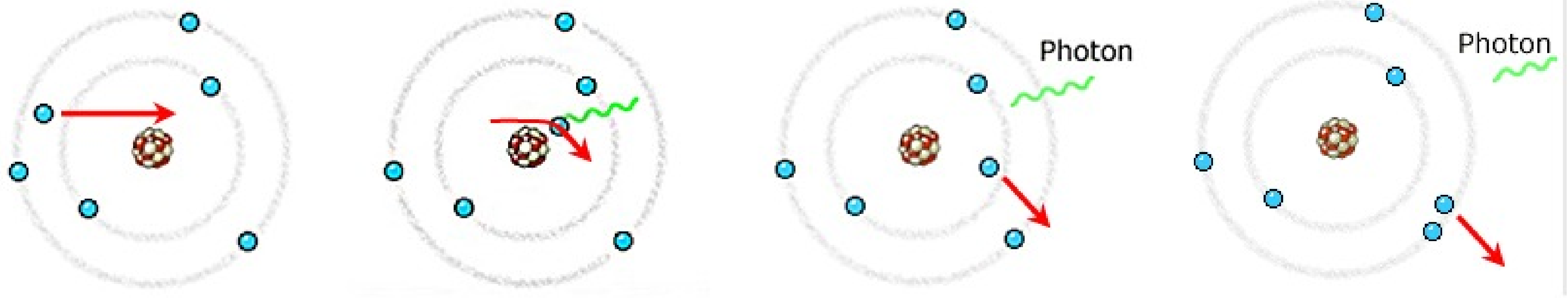


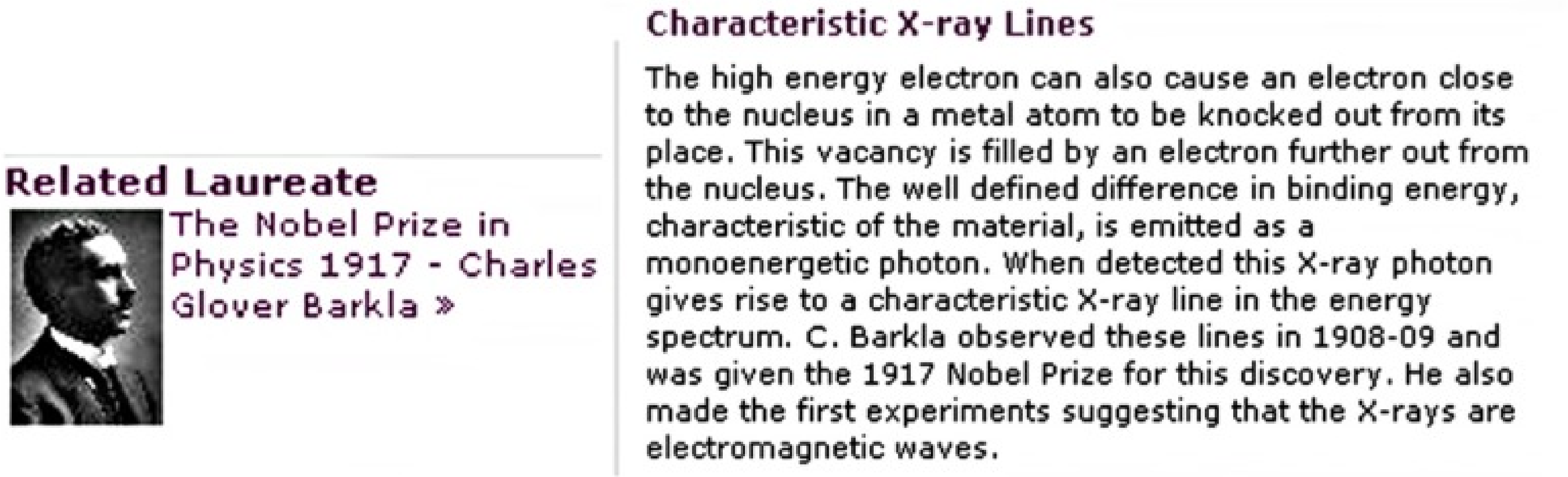
Figure 1.5. (a) Section along the axis of an X-ray tube. (b, Anode with focal spot viewed from side. (c) Focal spot viewed through tube window.

The electron (much lighter than the nucleus) comes very close to the nucleus and the electromagnetic interaction causes a deviation of the trajectory where the electron looses energy and an X-ray photon is emitted.

Bremsstrahlung X-rays

In an X-ray tube the electrons emitted from the anode are accelerated towards the metal target cathode by an accelerating voltage of typically 50 kV. The high energy electrons interact with the atoms in the metal target. Sometimes the electron comes very close to a nucleus in the target and is deviated by the electromagnetic interaction. In this process, which is called bremsstrahlung (braking radiation), the electron looses much energy and a photon (X-ray) is emitted. The energy of the emitted photon can take any value up to a maximum corresponding to the energy of the incident electron.



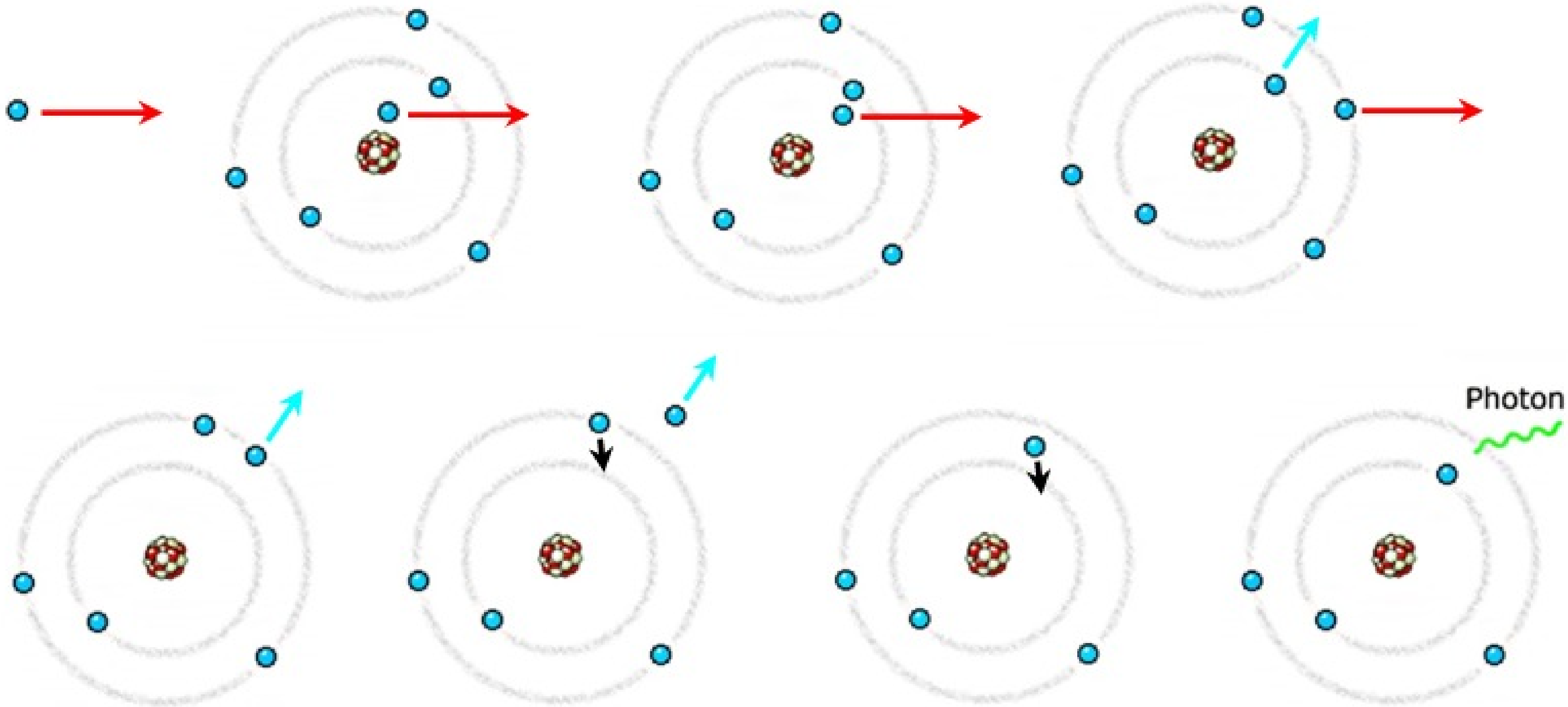


Related Laureate

The Nobel Prize in Physics 1917 - Charles Glover Barkla »

Characteristic X-ray Lines

The high energy electron can also cause an electron close to the nucleus in a metal atom to be knocked out from its place. This vacancy is filled by an electron further out from the nucleus. The well defined difference in binding energy, characteristic of the material, is emitted as a monoenergetic photon. When detected this X-ray photon gives rise to a characteristic X-ray line in the energy spectrum. C. Barkla observed these lines in 1908-09 and was given the 1917 Nobel Prize for this discovery. He also made the first experiments suggesting that the X-rays are electromagnetic waves.



Characteristic X-rays arise from electronic transitions

$K_{\alpha_1}, K_{\alpha_2}$ $L \to K$

K_{β_1}, K_{β_2} $M \to K$

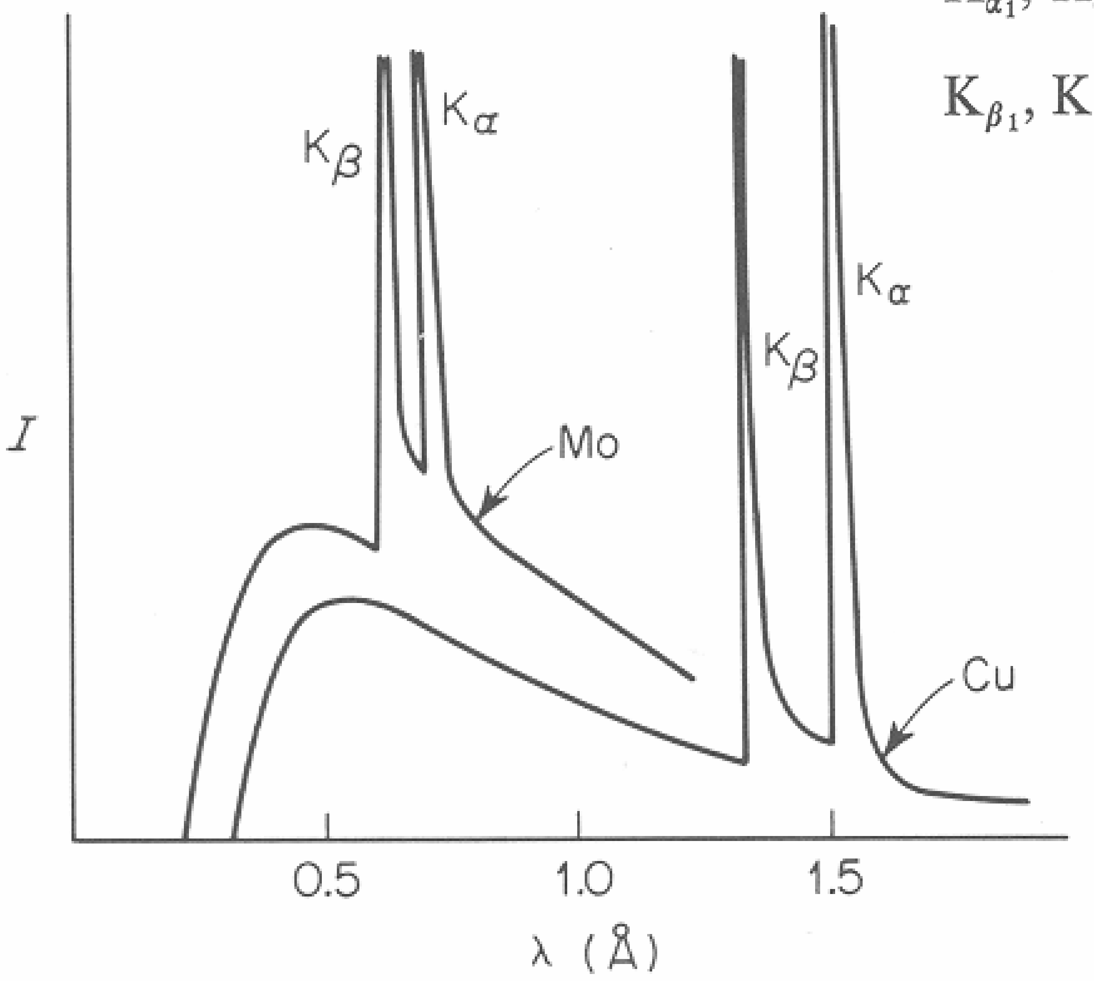
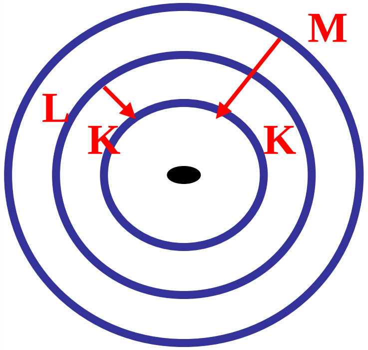


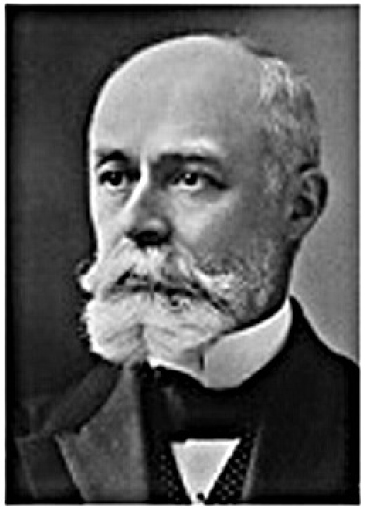
Figure 1.2. X-ray spectra with characteristic peaks: MoKα, 50 Kv; CuKα, 35 Kv.



The Nobel Prize in Physics 1903

"in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity"

"in recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel"



Antoine Henri Becquerel

◐ 1/2 of the prize

France

Pierre Curie

◔ 1/4 of the prize

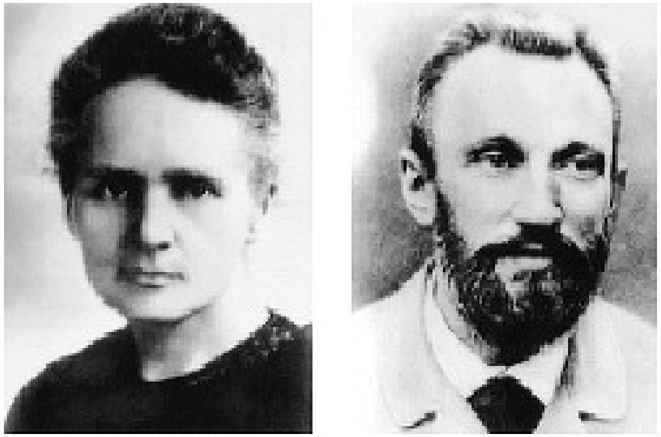
France

Marie Curie, née Sklodowska

◔ 1/4 of the prize

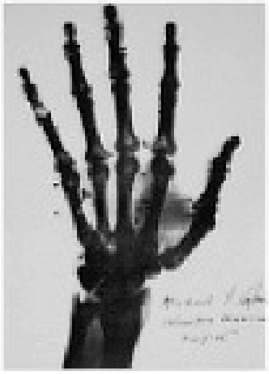
France

Marie and
Pierre
Curie

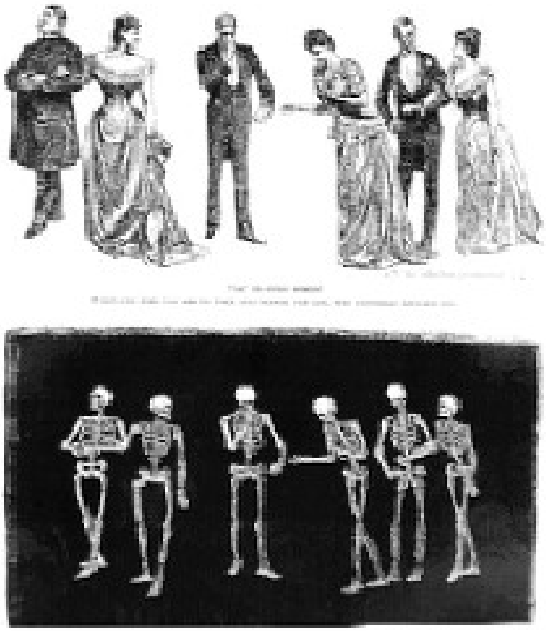


Marie Sklodowska Curie
1867-1934

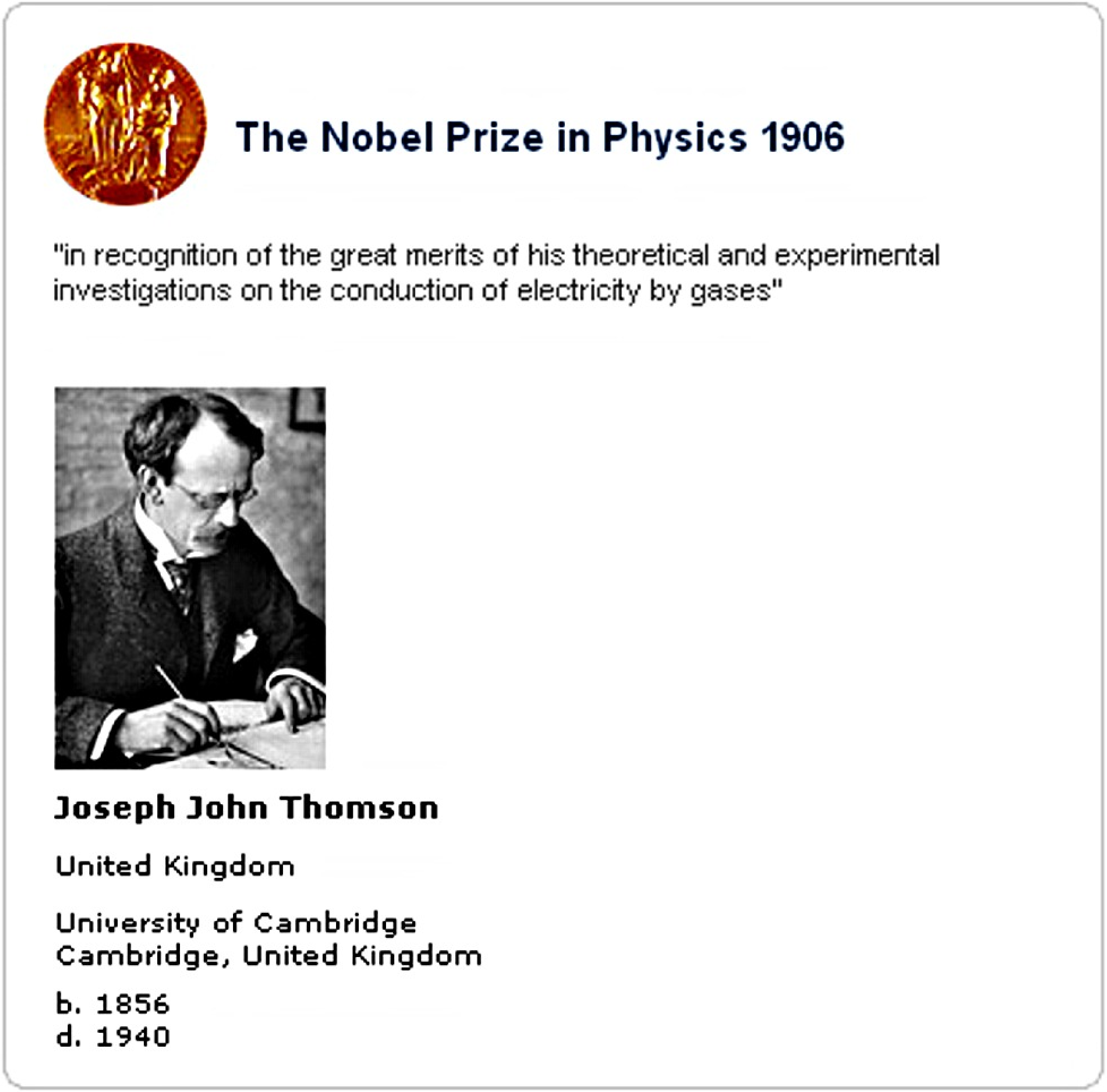
Pierre Curie
1859-1906



Revelations of an X-ray.



See "Women in Chemistry" in our S 2000
"Chemical Compositions" newsletter, p.4)



The Nobel Prize in Physics 1906

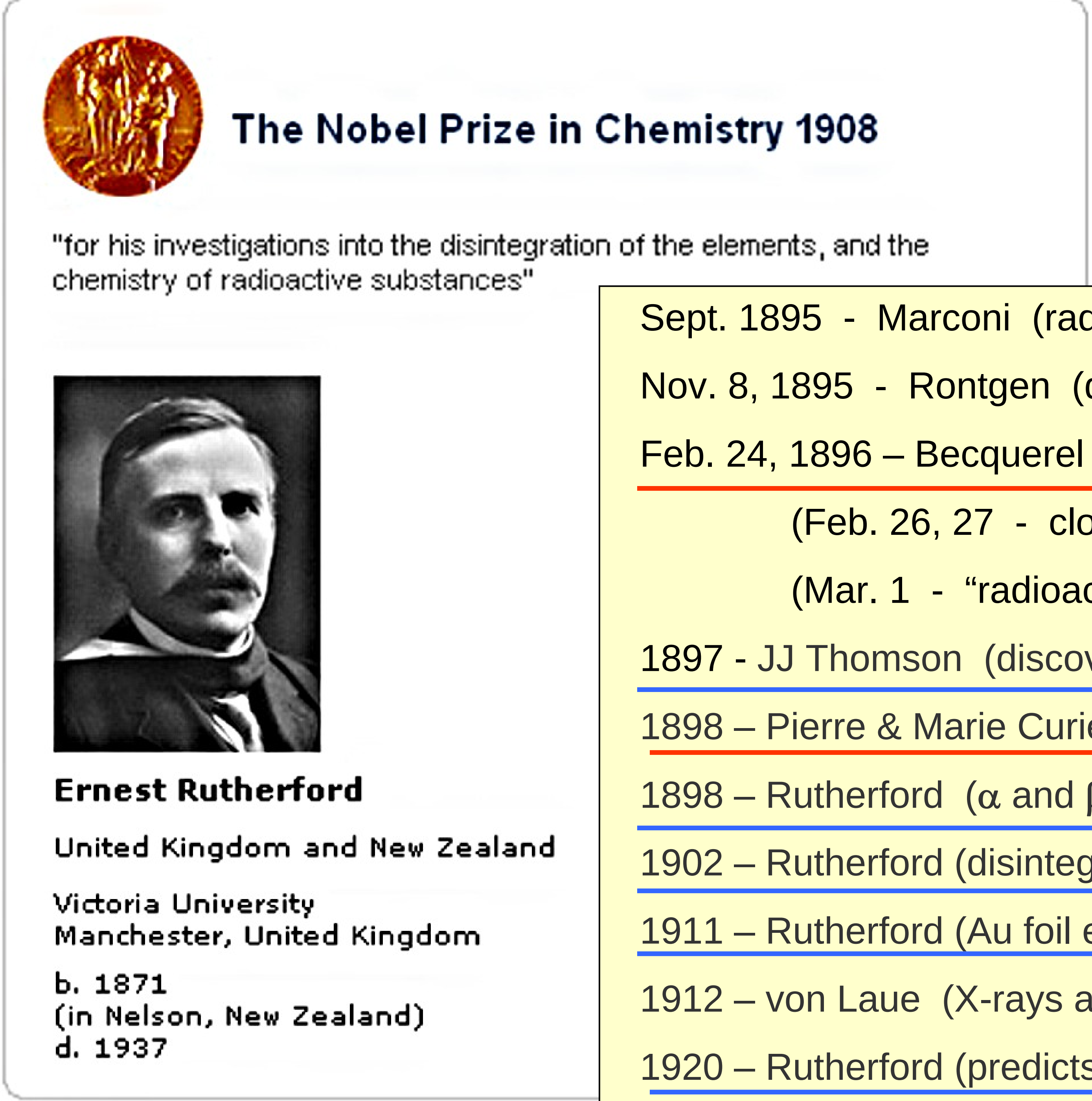
"in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases"

Joseph John Thomson

United Kingdom

University of Cambridge
Cambridge, United Kingdom

b. 1856
d. 1940



The Nobel Prize in Chemistry 1908

"for his investigations into the disintegration of the elements, and the chemistry of radioactive substances"

Ernest Rutherford

United Kingdom and New Zealand

Victoria University
Manchester, United Kingdom

b. 1871
(in Nelson, New Zealand)
d. 1937

Sept. 1895 - Marconi (radio waves / wireless)

Nov. 8, 1895 - Rontgen (discovery of X-rays)

Feb. 24, 1896 – Becquerel (U luminesce")

(Feb. 26, 27 - cloudy days)

(Mar. 1 - "radioactivity")

1897 - JJ Thomson (discovery of electrons)

1898 – Pierre & Marie Curie (Po, Ra)

1898 – Rutherford (α and β radiation)

1902 – Rutherford (disintegration of elements)

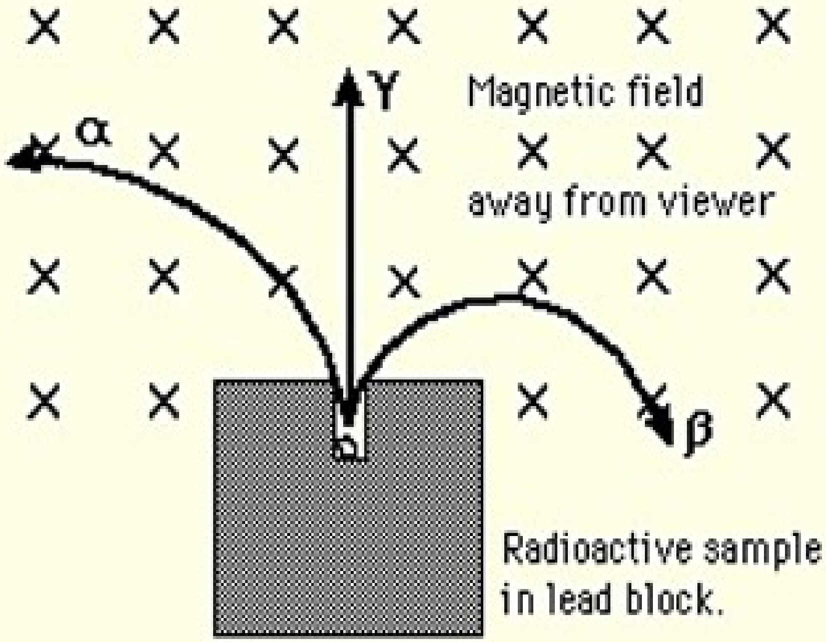
1911 – Rutherford (Au foil exp. / nuclear atom)

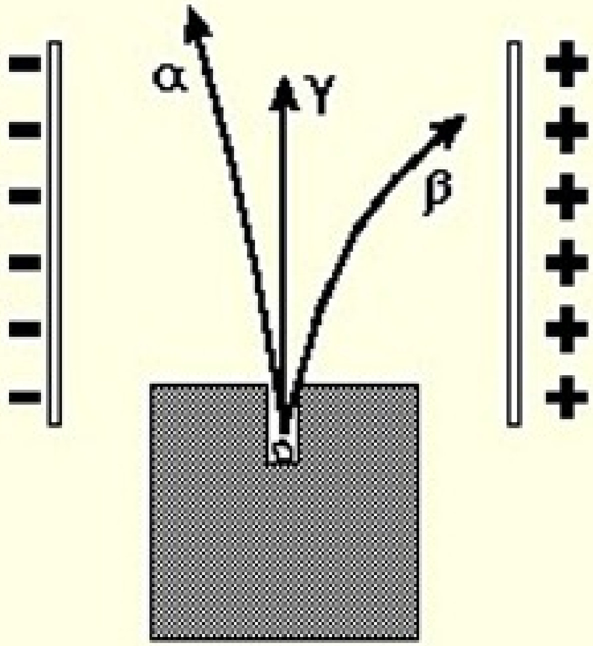
1912 – von Laue (X-rays as waves)

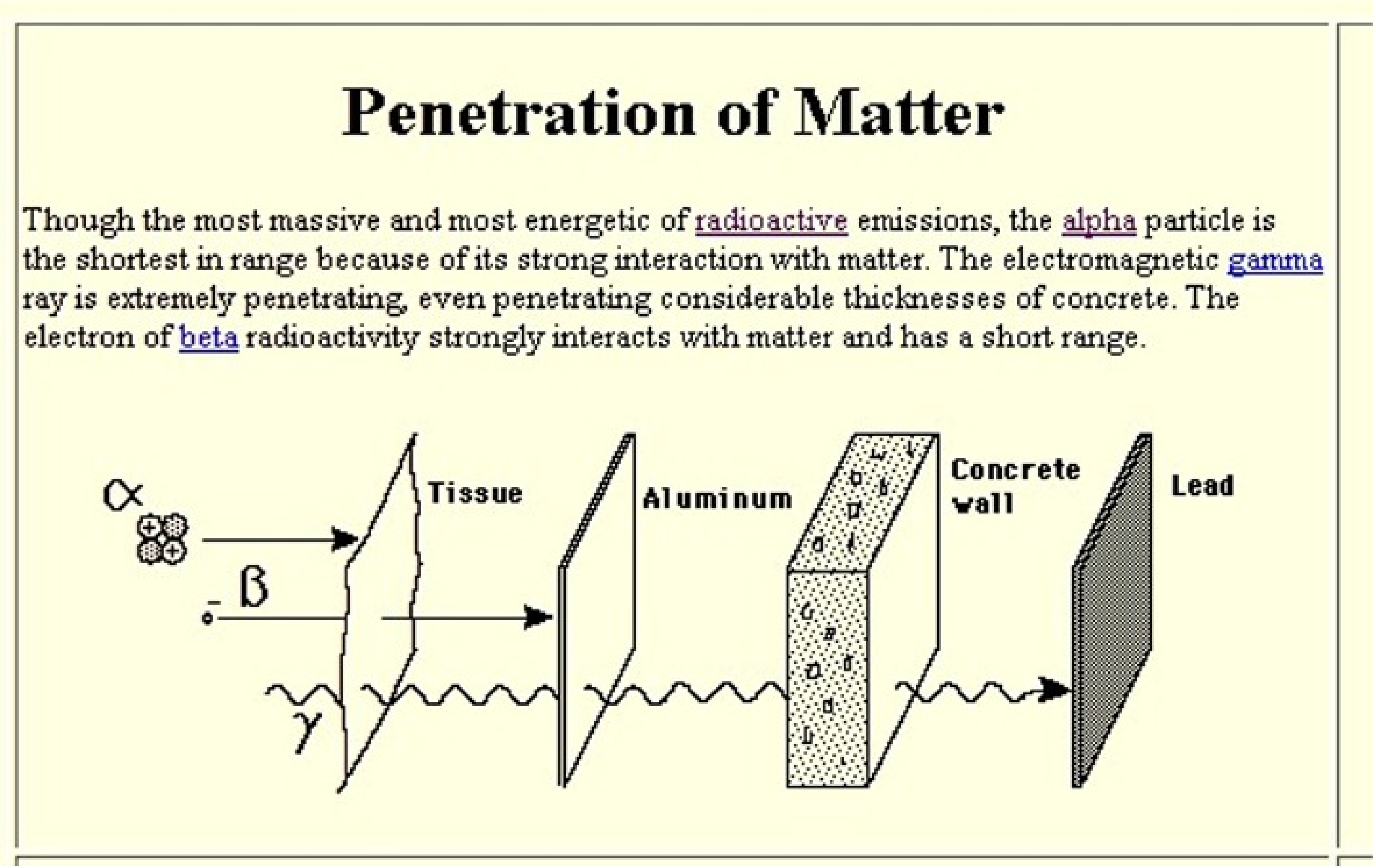
1920 – Rutherford (predicts neutron)

Alpha, Beta, and Gamma

Historically, the products of radioactivity were called alpha, beta, and gamma when it was found that they could be analyzed into three distinct species by either a magnetic field or an electric field.





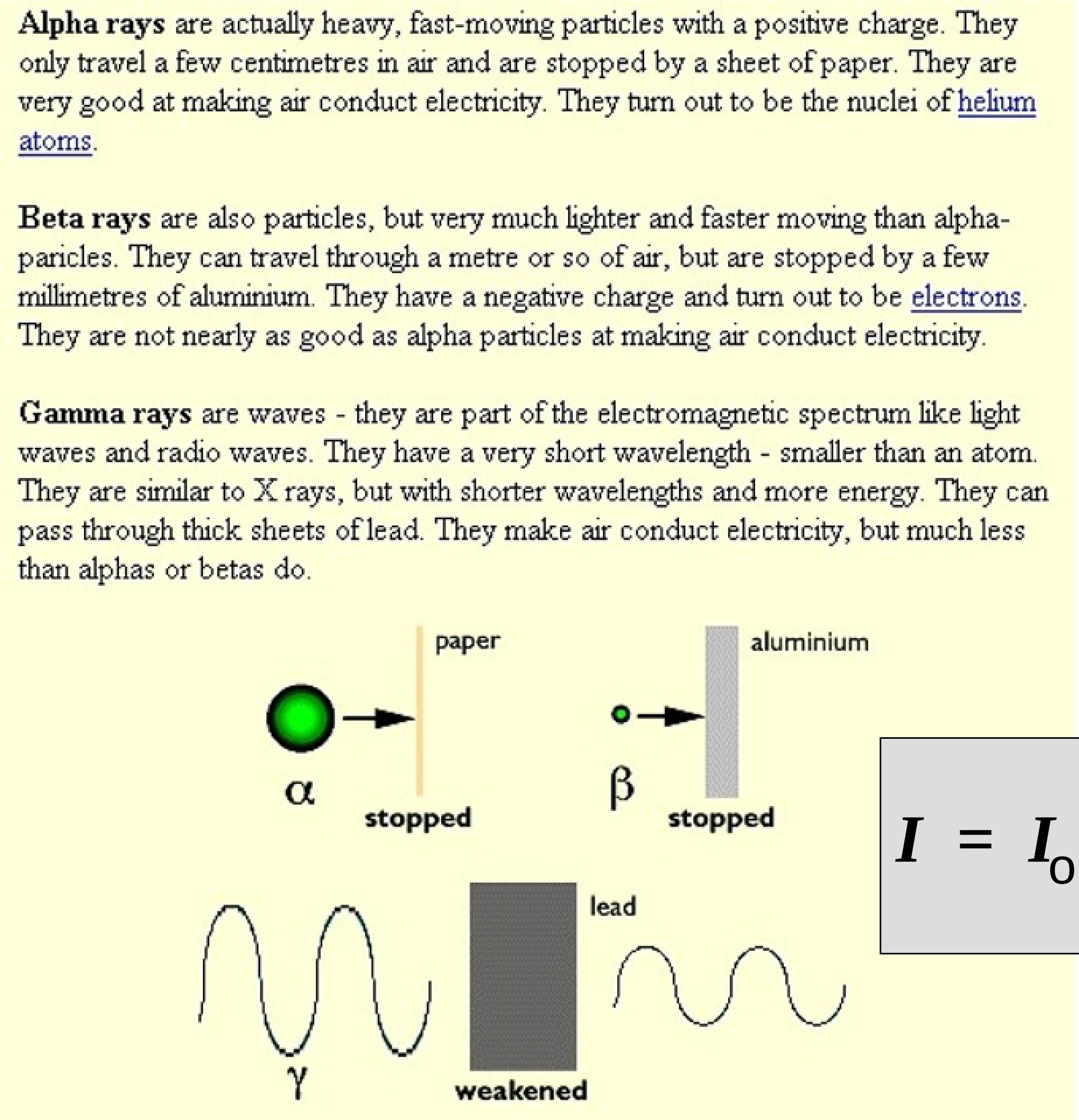


Penetration of Matter

Though the most massive and most energetic of radioactive emissions, the alpha particle is the shortest in range because of its strong interaction with matter. The electromagnetic gamma ray is extremely penetrating, even penetrating considerable thicknesses of concrete. The electron of beta radioactivity strongly interacts with matter and has a short range.

$$I = I_o e^{-\lambda t}$$

Rutherford – quantitative measurements



Alpha rays are actually heavy, fast-moving particles with a positive charge. They only travel a few centimetres in air and are stopped by a sheet of paper. They are very good at making air conduct electricity. They turn out to be the nuclei of helium atoms.

Beta rays are also particles, but very much lighter and faster moving than alpha-paricles. They can travel through a metre or so of air, but are stopped by a few millimetres of aluminium. They have a negative charge and turn out to be electrons. They are not nearly as good as alpha particles at making air conduct electricity.

Gamma rays are waves - they are part of the electromagnetic spectrum like light waves and radio waves. They have a very short wavelength - smaller than an atom. They are similar to X rays, but with shorter wavelengths and more energy. They can pass through thick sheets of lead. They make air conduct electricity, but much less than alphas or betas do.

$$I = I_o e^{-\lambda t}$$

Mass Number = #p + #n

Atomic Number = # protons

$$^{238}_{92}\text{U}$$

Radioactive Decay

Remember that the lower number is the atomic number and the upper number is the mass number.

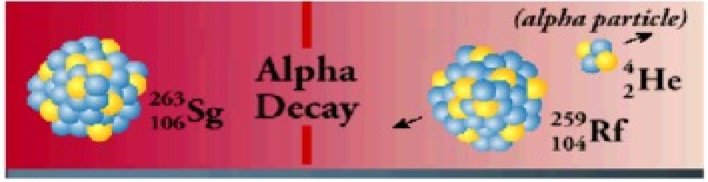
Alpha Decay

In 1899, Ernest Rutherford wrote the following words:

"These experiments show that the uranium radiation is complex and that there are present at least two distinct types of radiation - one that is very readily absorbed, which will be termed for convenience the alpha-radiation, and the other of more penetrative character which will be termed the beta-radiation."

The image to the right is of a twenty-eight year old Ernest Rutherford while at McGill University in 1899.

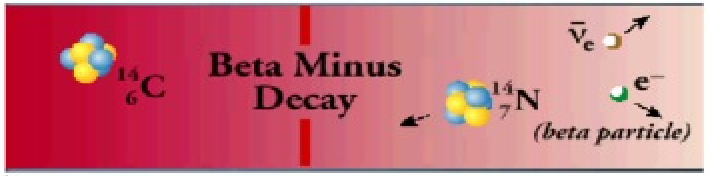
Alpha



$$^{222}_{88}\text{Ra} \longrightarrow {}^{4}_{2}\text{He} + {}^{218}_{86}\text{Rn}$$

Ernest Rutherford
1899

Beta -



$$^{14}_{6}\text{C} \longrightarrow {}^{14}_{7}\text{N} + {}^{0}_{-1}\text{e} + {}^{0}_{0}\bar{\nu}$$

b)

Beta +
(positron)

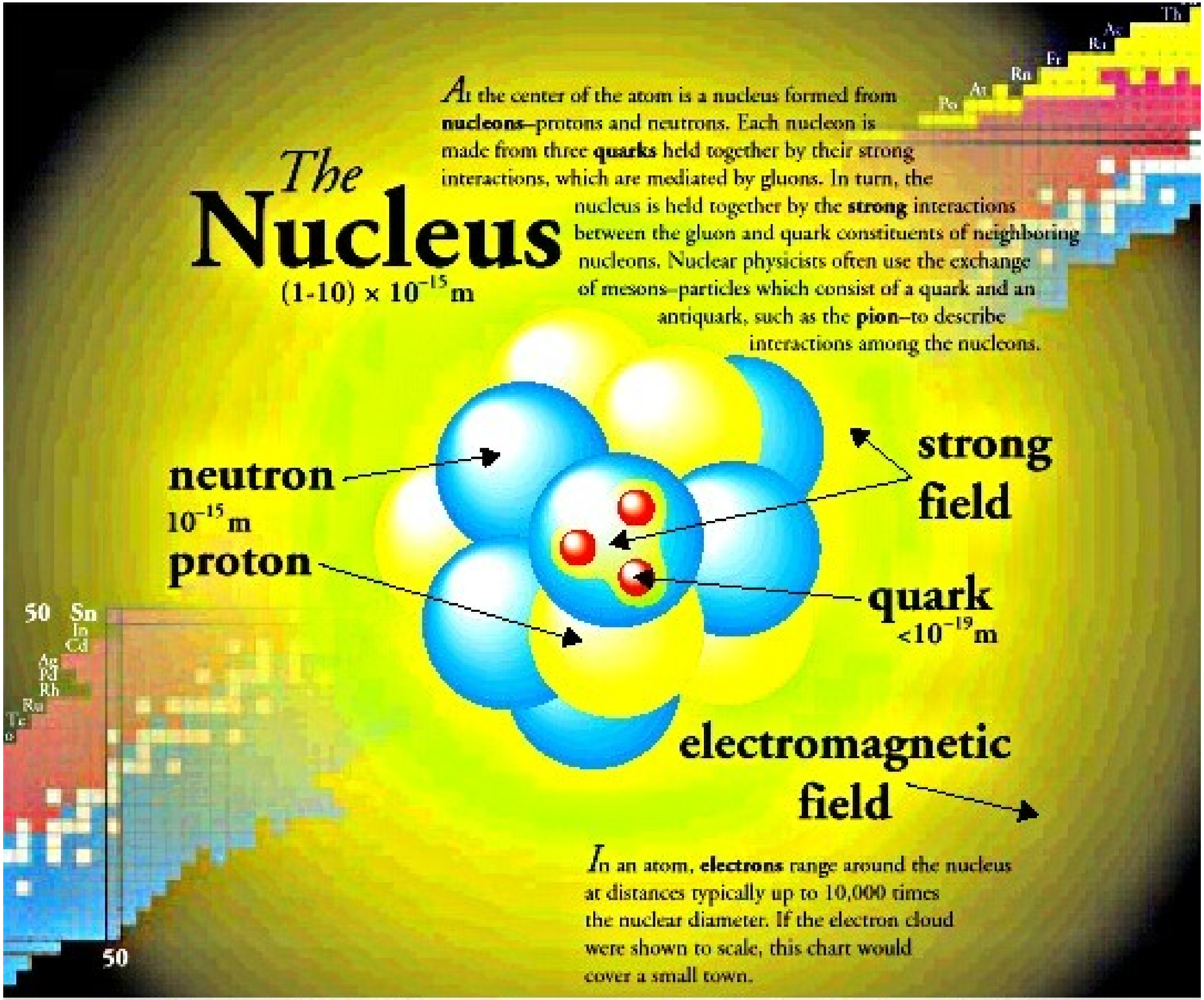
$$^{50}_{25}\text{Mn} \longrightarrow {}^{50}_{24}\text{Cr} + {}^{0}_{+1}\text{e} + {}^{0}_{0}\nu$$

Gamma
Emission

Electron
Capture

$$^{81}_{36}\text{Kr} + {}^{0}_{-1}\text{e} \longrightarrow {}^{81}_{35}\text{Br} + {}^{0}_{0}\nu$$

Nuclear Wall Chart - Lawrence Berkeley National Laboratory
Contemporary Physics Education Project (CPEP)



The Nucleus

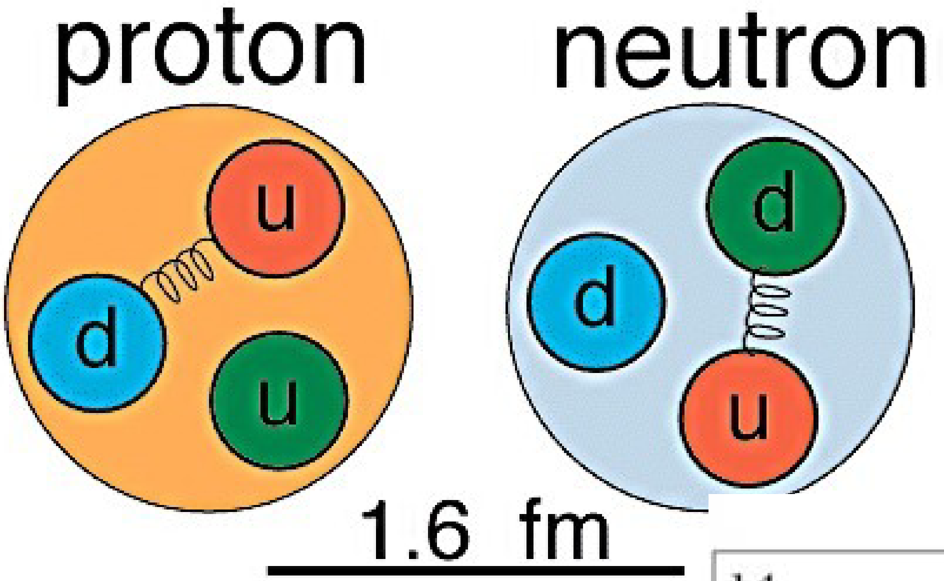
(1-10) × 10^{-15} m

At the center of the atom is a nucleus formed from **nucleons**–protons and neutrons. Each nucleon is made from three **quarks** held together by their strong interactions, which are mediated by gluons. In turn, the nucleus is held together by the **strong** interactions between the gluon and quark constituents of neighboring nucleons. Nuclear physicists often use the exchange of mesons–particles which consist of a quark and an antiquark, such as the **pion**–to describe interactions among the nucleons.

In an atom, **electrons** range around the nucleus at distances typically up to 10,000 times the nuclear diameter. If the electron cloud were shown to scale, this chart would cover a small town.

Nuclear Wall Chart - Lawrence Berkeley National Laboratory
Contemporary Physics Education Project (CPEP)

Protons and **Neutrons** are both made up of **Quarks**. In the **Quark Model** the only difference between a **Proton** and a **Neutron** is that an “**up**” **Quark** has been replaced by a “**down**” **Quark**.



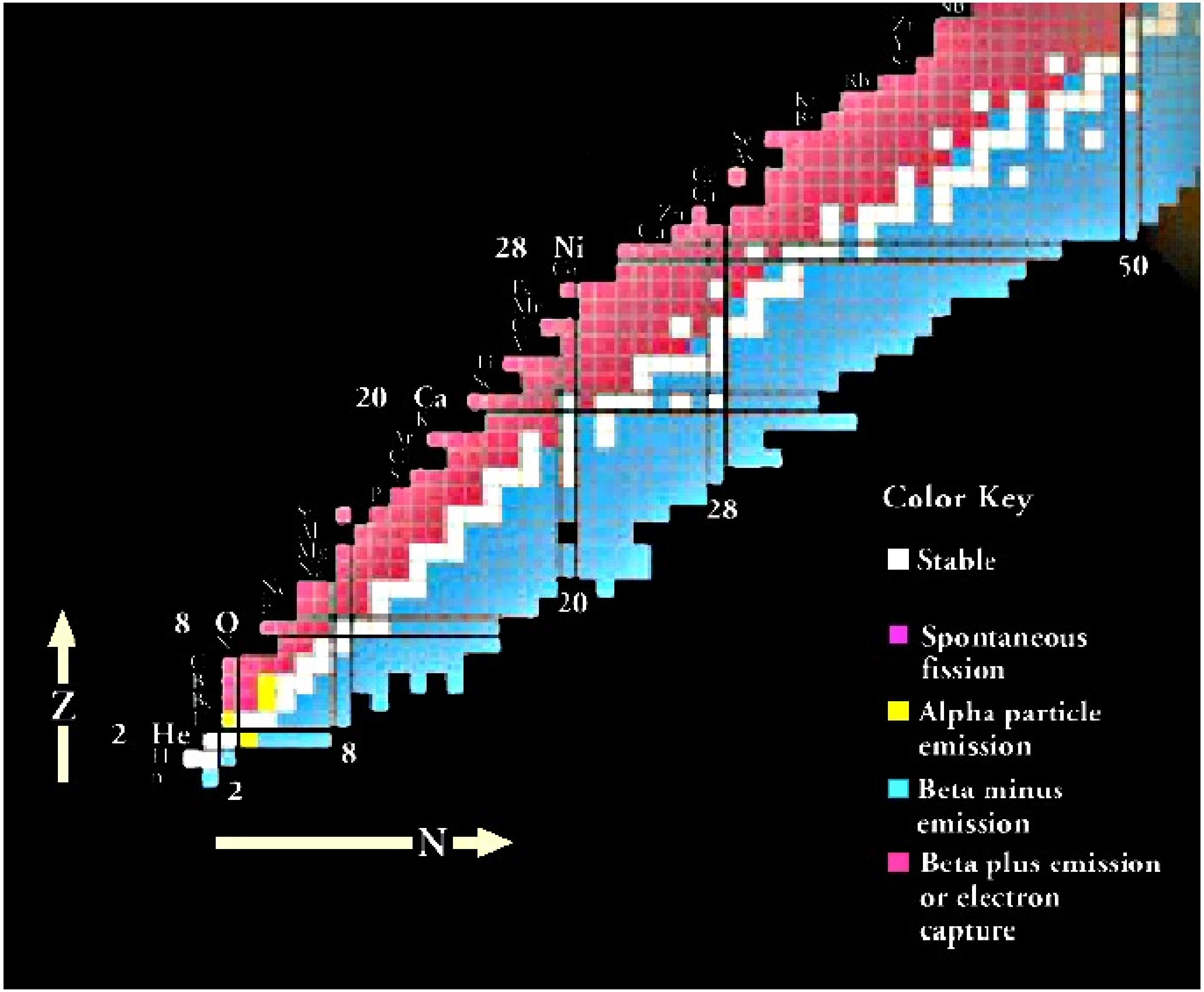
$$^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e} + {}^{0}_{0}\bar{\nu}$$

The little spring in the drawing is used
to indicate that the quarks inside a nucleon
are held together by a force we call gluon exchange.

Size of Nucleons

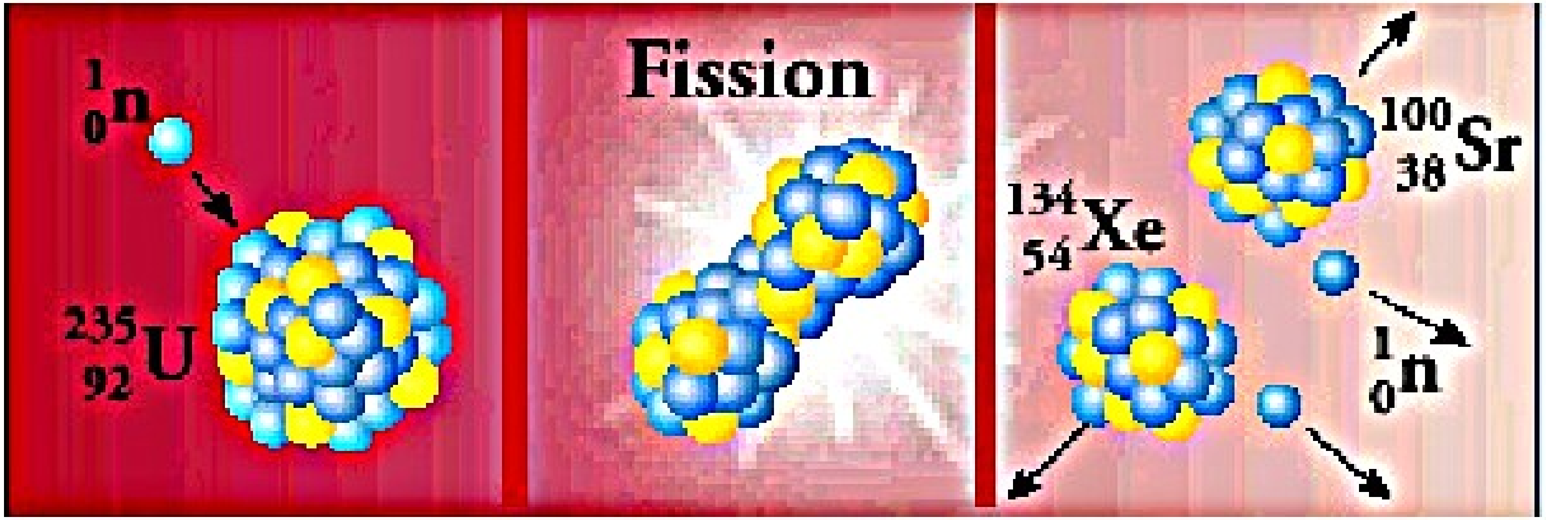
Nuclear Wall Chart - Lawrence Berkeley National Laboratory
Contemporary Physics Education Project (CPEP)

Of the nuclei found on Earth, the vast majority are stable. This is because almost all short-lived radioactive nuclei have decayed during the history of the Earth. There are approximately 270 stable isotopes and 50 naturally occurring radioisotopes (radioactive isotopes). Thousands of other radioisotopes have been made in the laboratory.



Nuclear Wall Chart - Lawrence Berkeley National Laboratory
Contemporary Physics Education Project (CPEP)

Nuclear Fission Energy



Fission of ^{235}U after absorption of a thermal neutron.

The relevant nuclear reactions can be written as follows:

$$^{235}U + {}^{1}n \rightarrow \text{fission products} + \text{neutrons} + \text{energy } (\sim 200 \text{ MeV}) \quad (1)$$

$$^{238}U + {}^{1}n \rightarrow {}^{239}U + \text{gamma rays} \quad (2)$$

$$^{239}U \rightarrow {}^{239}Np \rightarrow {}^{239}Pu \qquad \text{(a series of beta decays).} \quad (3)$$

Nuclear Wall Chart - Lawrence Berkeley National Laboratory
Contemporary Physics Education Project (CPEP)

Characteristics of Biologically Significant Isotopes

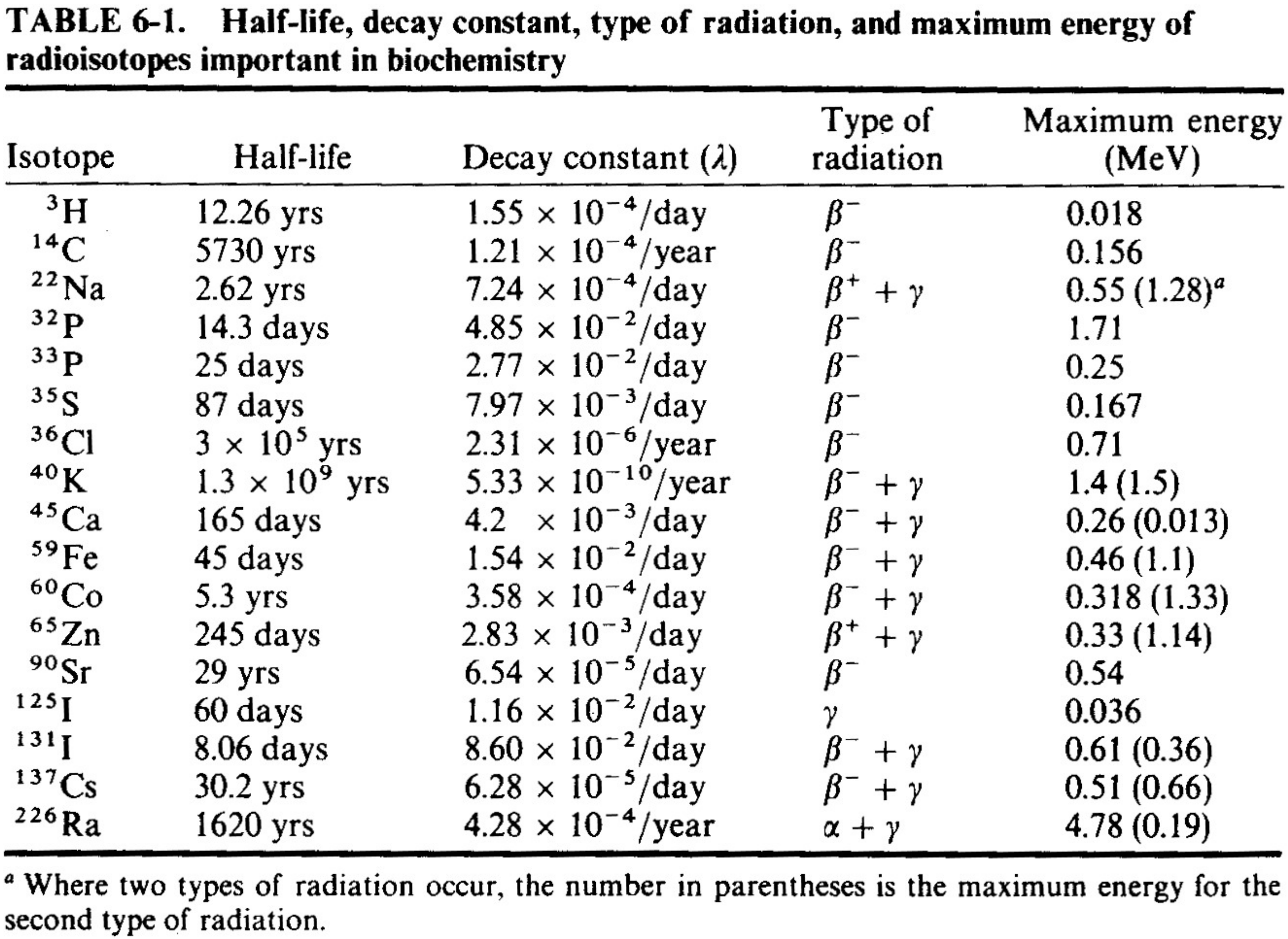


TABLE 6-1. Half-life, decay constant, type of radiation, and maximum energy of radioisotopes important in biochemistry

Isotope	Half-life	Decay constant (λ)	Type of radiation	Maximum energy (MeV)
^{3}H	12.26 yrs	1.55×10^{-4}/day	β^-	0.018
^{14}C	5730 yrs	1.21×10^{-4}/year	β^-	0.156
^{22}Na	2.62 yrs	7.24×10^{-4}/day	$\beta^+ + \gamma$	0.55 (1.28)[a]
^{32}P	14.3 days	4.85×10^{-2}/day	β^-	1.71
^{33}P	25 days	2.77×10^{-2}/day	β^-	0.25
^{35}S	87 days	7.97×10^{-3}/day	β^-	0.167
^{36}Cl	3×10^{5} yrs	2.31×10^{-6}/year	β^-	0.71
^{40}K	1.3×10^{9} yrs	5.33×10^{-10}/year	$\beta^- + \gamma$	1.4 (1.5)
^{45}Ca	165 days	4.2×10^{-3}/day	$\beta^- + \gamma$	0.26 (0.013)
^{59}Fe	45 days	1.54×10^{-2}/day	$\beta^- + \gamma$	0.46 (1.1)
^{60}Co	5.3 yrs	3.58×10^{-4}/day	$\beta^- + \gamma$	0.318 (1.33)
^{65}Zn	245 days	2.83×10^{-3}/day	$\beta^+ + \gamma$	0.33 (1.14)
^{90}Sr	29 yrs	6.54×10^{-5}/day	β^-	0.54
^{125}I	60 days	1.16×10^{-2}/day	γ	0.036
^{131}I	8.06 days	8.60×10^{-2}/day	$\beta^- + \gamma$	0.61 (0.36)
^{137}Cs	30.2 yrs	6.28×10^{-5}/day	$\beta^- + \gamma$	0.51 (0.66)
^{226}Ra	1620 yrs	4.28×10^{-4}/year	$\alpha + \gamma$	4.78 (0.19)

[a] Where two types of radiation occur, the number in parentheses is the maximum energy for the second type of radiation.

$$\boxed{t_{1/2} = \frac{0.693}{\lambda}}$$

$$I = I_o\, e^{-\lambda t}$$

Since nuclear radiation affects people, we must be able to measure radioactivity. We also need to relate the amount of radiation received by the body to its physiological effects. Two terms used to relate the amount of radiation received by the body are exposure and dose.

Radioactivity

Original unit - amt of **radioactivity** was the ***curie*** **(Ci) -** activity of one gram of radium-226.

Today ***1 curie = 3.7 10+10 radioactive decays per second*** [exactly].

International System of Units (SI) the **becquerel (Bq)** has replaced the curie, where

1 becquerel = 1 radioactive decay per second = ***2.703 10-11 Ci***.

The magnitude of radiation ***exposures*** *is specified in terms of the* ***radiation dose****.*

Exposure:

Roentgen - It is the **amount of radiation** required to liberate positive and negative charges of one esu of charge in 1 cm*3 at STP. This corresponds to the generation of approximately **2.08×10^9 ion pairs.**

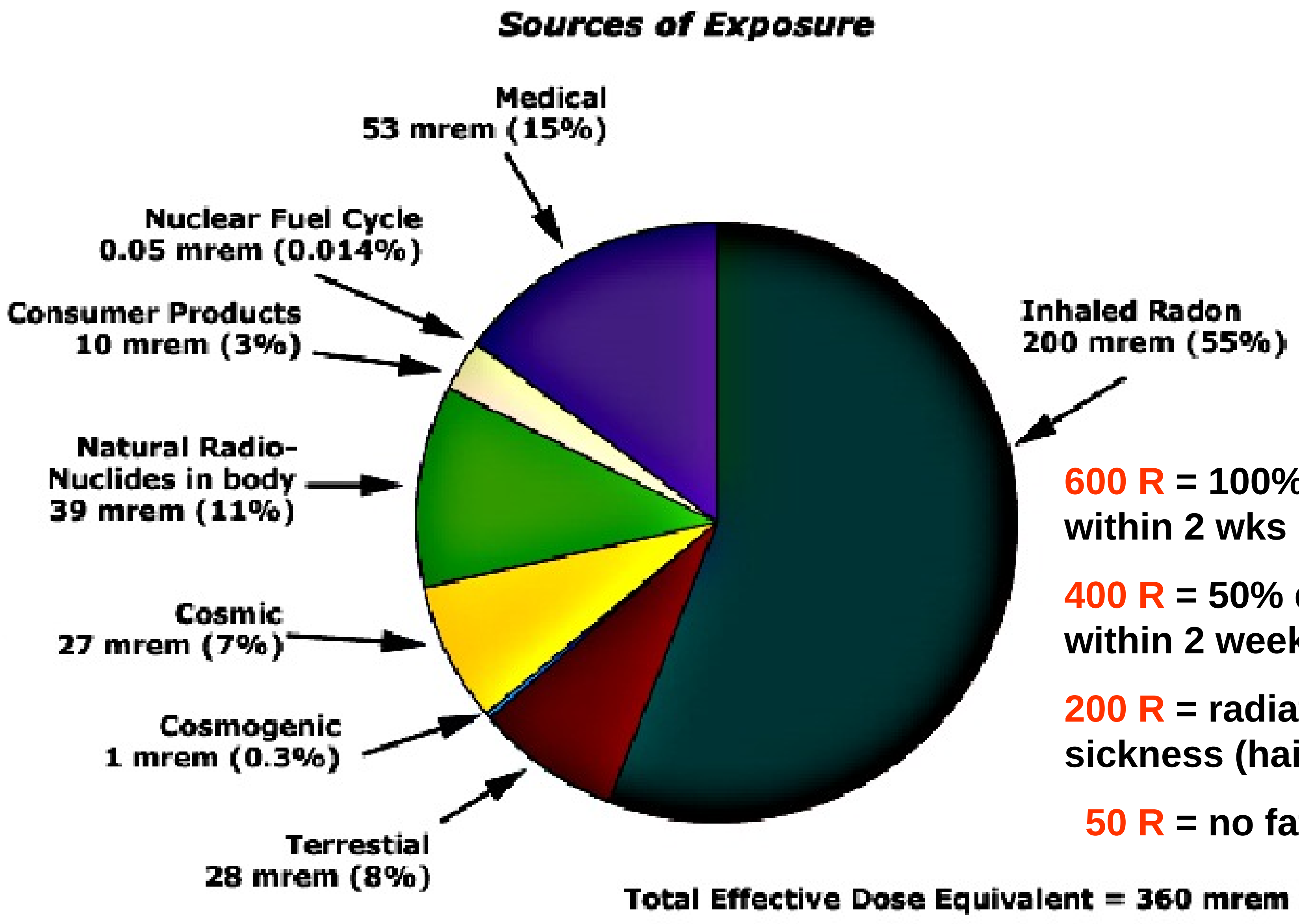
Dose:

There are two important categories of ***dose****:*

1. ***Rad****:* ***radiation absorbed dose****, also known as the* ***physical dose****, defined by the amount of energy deposited in a unit mass in human tissue. The original unit is the* ***rad [100 erg/g]****; it is now being widely replaced by the* ***SI unit, the*** *gray (Gy) [1 J/kg], where* ***1 gray = 100 rad****.*

2. ***Rem****: The* ***Roentgen equivalent in man*** *or* ***biological dose*** *or* ***dose equivalent****, expressed in units of* ***rem*** *or, in the* ***SI system****,* ***sievert (Sv)****. This dose reflects the fact that the biological damage caused by a particle depends not only on the total energy deposited but also on the rate of energy loss per unit distance traversed by the particle (or "****linear energy transfer****").* ***(Q ~ 1 for gamma or beta; ~ 5 protons; ~ 20 for alpha particles.)***

1 Sv = 100 rem. 1 rem is the average dose received in 3 years of exposure to natural radiation.



600 R = 100% dead within 2 wks

400 R = 50% die within 2 weeks

200 R = radiation sickness (hair loss)

50 R = no fatalities

Natural Background Radiation = 295 mrem (82%)
Manmade Radiation = medical + consumer products = 63 mrem (18%)

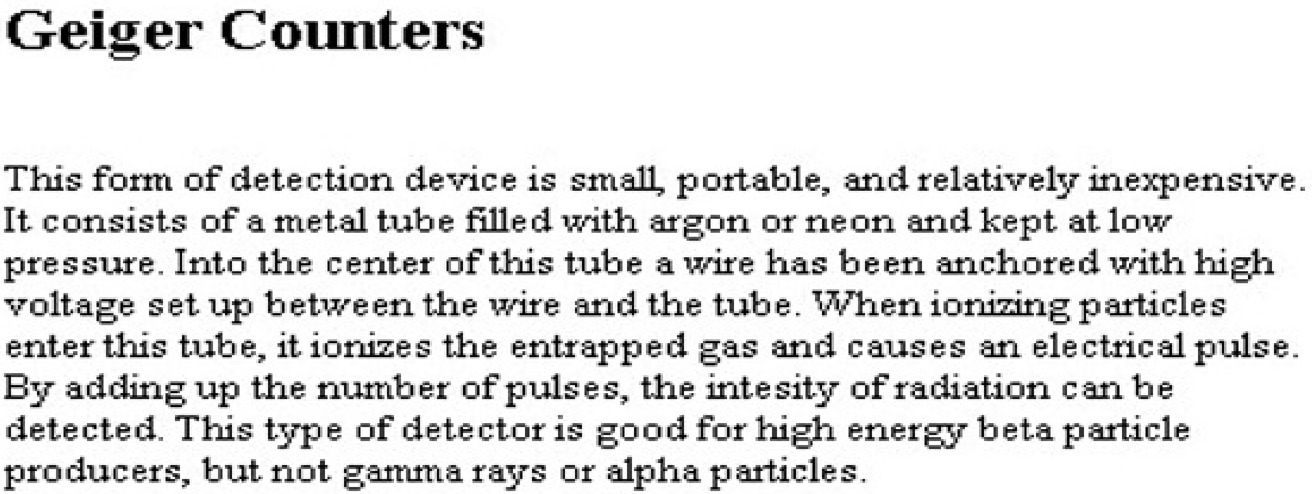
Counting Radioactivity

1) Film

2) Geiger Counter

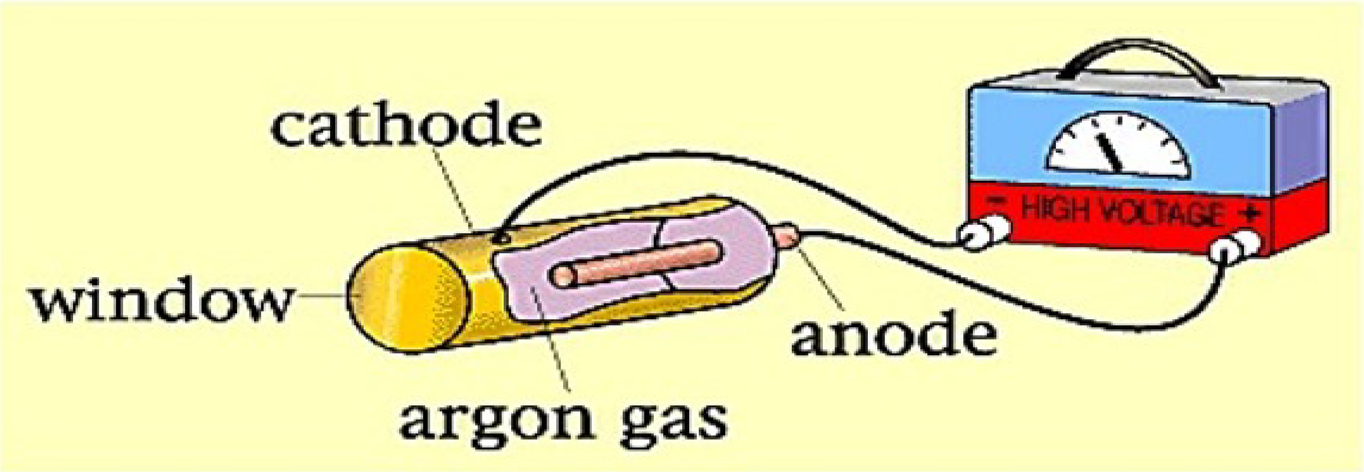
3) Liquid Scintillation Counters

4) PhosphorImager



Geiger Counters

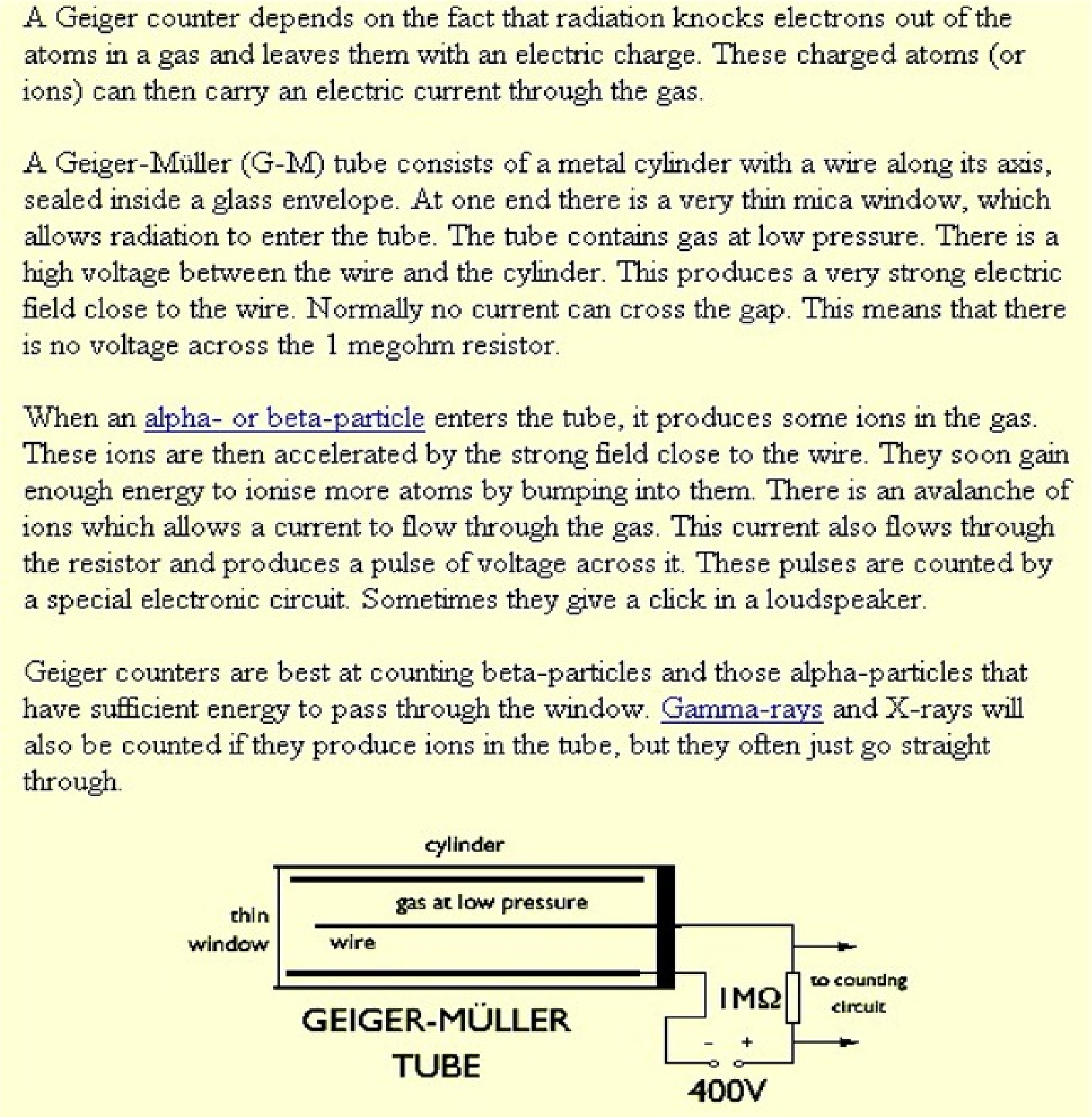
This form of detection device is small, portable, and relatively inexpensive. It consists of a metal tube filled with argon or neon and kept at low pressure. Into the center of this tube a wire has been anchored with high voltage set up between the wire and the tube. When ionizing particles enter this tube, it ionizes the entrapped gas and causes an electrical pulse. By adding up the number of pulses, the intesity of radiation can be detected. This type of detector is good for high energy beta particle producers, but not gamma rays or alpha particles.



Hans Geiger worked as a lab tech for Rutherford for 5 years counting subatomic particles in a dark room using a screen and a microscope!

Geiger moved from England to teach in Germany in 1907 and quickly he perfected an automatic way to count these particles (tic tic tic tic ….).


OCDM ITEM NO. CDV-700
MODEL NO. 6A SER. NO.
THE VICTOREEN INSTRUMENT CO.
CLEVELAND, OHIO
OPERATIONAL
CHECK SOURCE



A Geiger counter depends on the fact that radiation knocks electrons out of the atoms in a gas and leaves them with an electric charge. These charged atoms (or ions) can then carry an electric current through the gas.

A Geiger-Müller (G-M) tube consists of a metal cylinder with a wire along its axis, sealed inside a glass envelope. At one end there is a very thin mica window, which allows radiation to enter the tube. The tube contains gas at low pressure. There is a high voltage between the wire and the cylinder. This produces a very strong electric field close to the wire. Normally no current can cross the gap. This means that there is no voltage across the 1 megohm resistor.

When an alpha- or beta-particle enters the tube, it produces some ions in the gas. These ions are then accelerated by the strong field close to the wire. They soon gain enough energy to ionise more atoms by bumping into them. There is an avalanche of ions which allows a current to flow through the gas. This current also flows through the resistor and produces a pulse of voltage across it. These pulses are counted by a special electronic circuit. Sometimes they give a click in a loudspeaker.

Geiger counters are best at counting beta-particles and those alpha-particles that have sufficient energy to pass through the window. Gamma-rays and X-rays will also be counted if they produce ions in the tube, but they often just go straight through.

Liquid Scintillation Counting

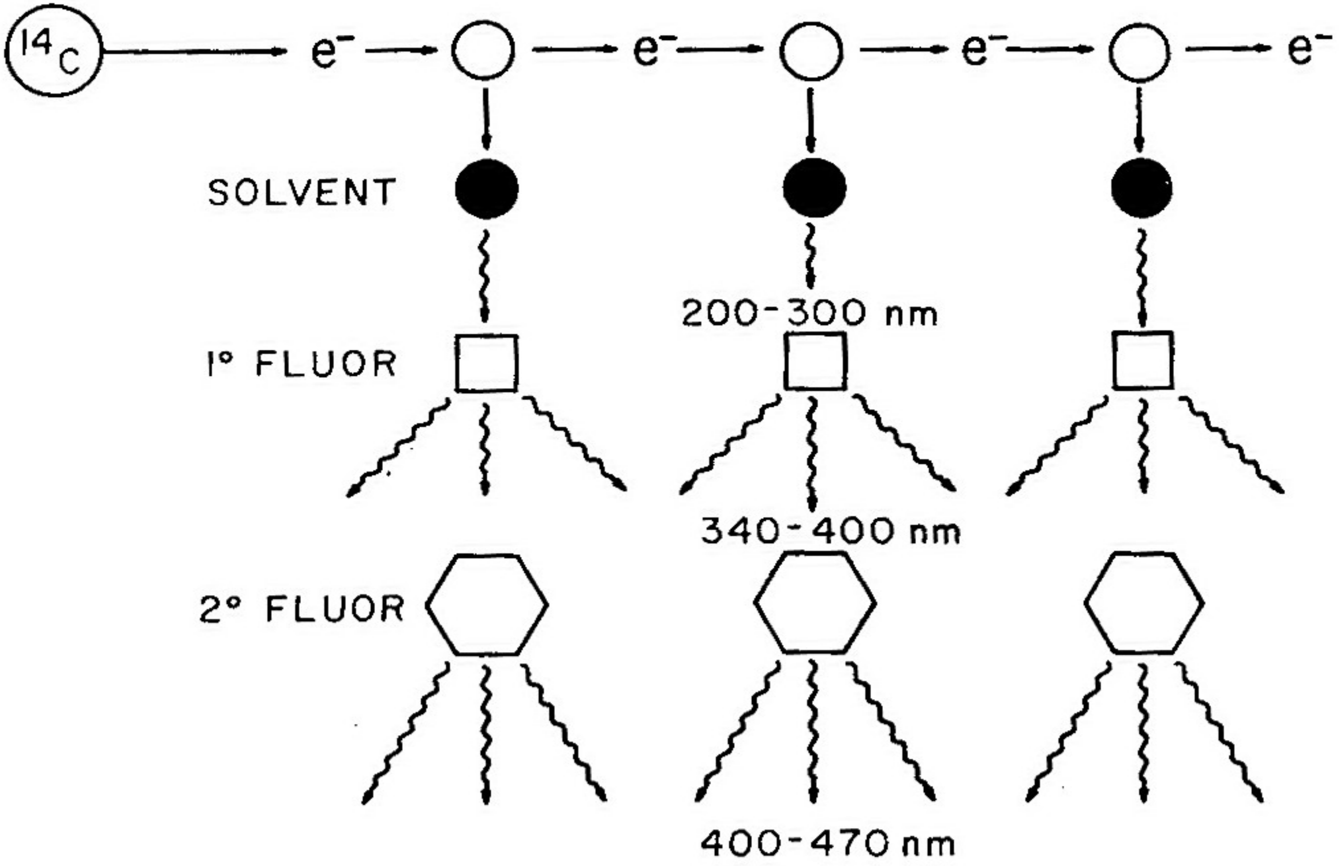
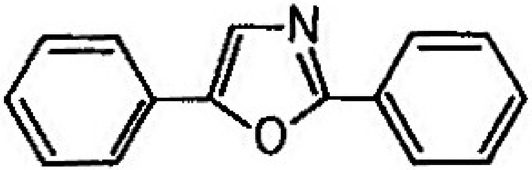


Figure 3-2. Interaction of β particles with aromatic solvents and subsequent fluor excitation. e^- represents the emitted β particles, ○ indicates a solvent molecule in its ground state, and ● denotes solvent molecules in the triplet state. (From E. Rapkin, *Preparation of Samples for Liquid Scintillation Counting*, Picker Nuclear Corp., White Plains, New York.)

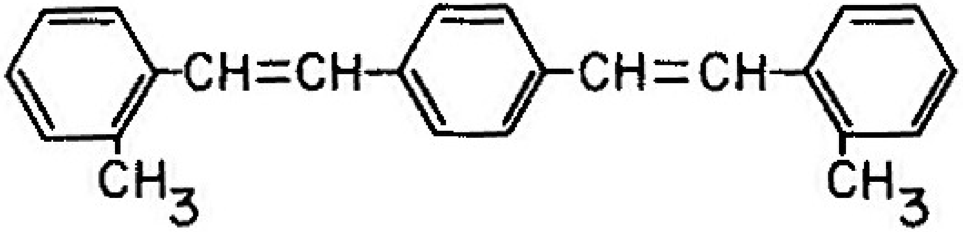


PPO

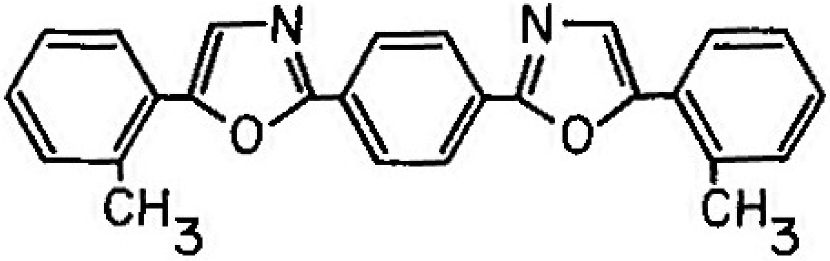
λ_f ~ 365 / 380

2,5-diphenyloxazole

(phenyl-oxazole-phenyl)



bis-MSB



dimethyl-POPOP

λ_f ~ 420 / 441

Photomultiplier Tubes

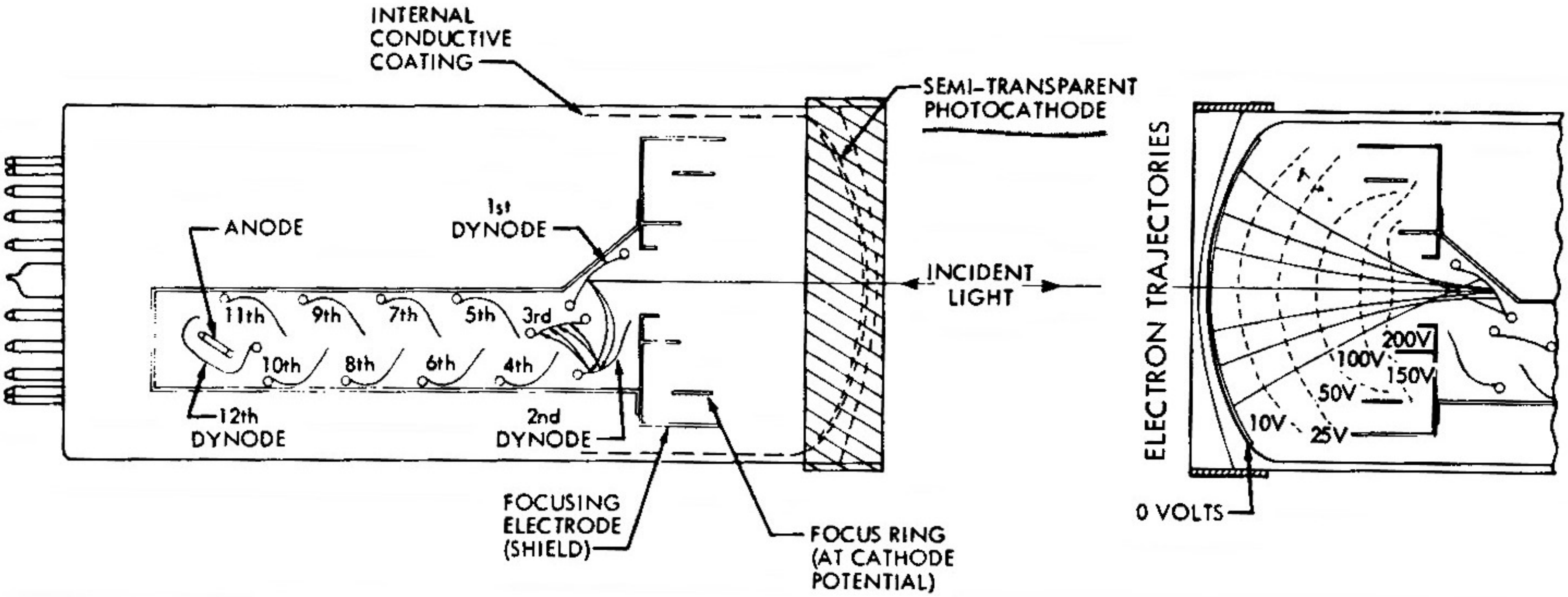


Figure 3-8. Beckman-RCA Bialkali 12-stage Photomultiplier Tube. (Courtesy of Beckman Instruments, Inc., Instruction Manual 1553-D.)

~ 10^{-9} seconds

$3\text{-}5\ e^-/e^-/$dynode

$\Rightarrow 1\,e^- \rightarrow 10^6\,e^-$

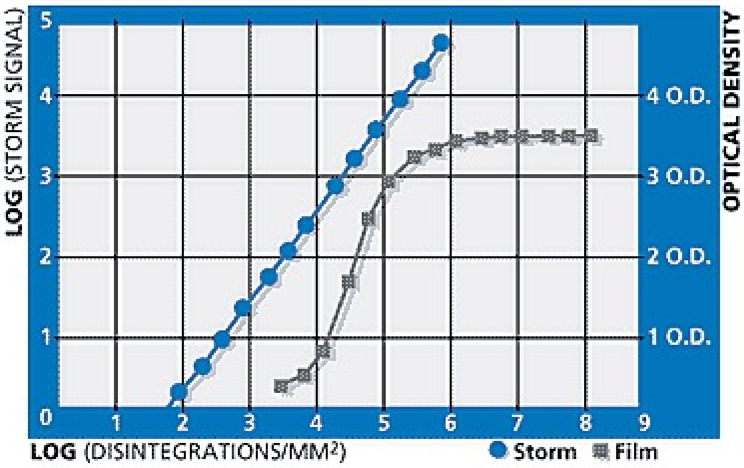
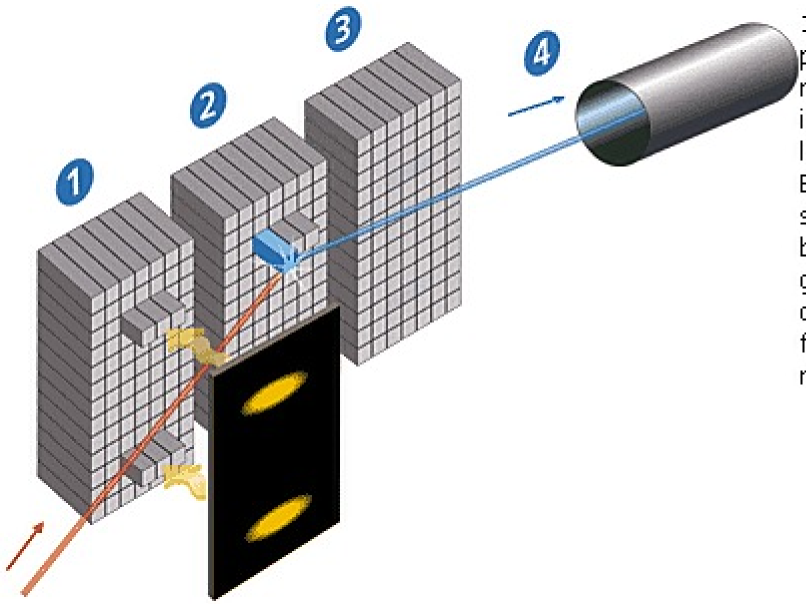


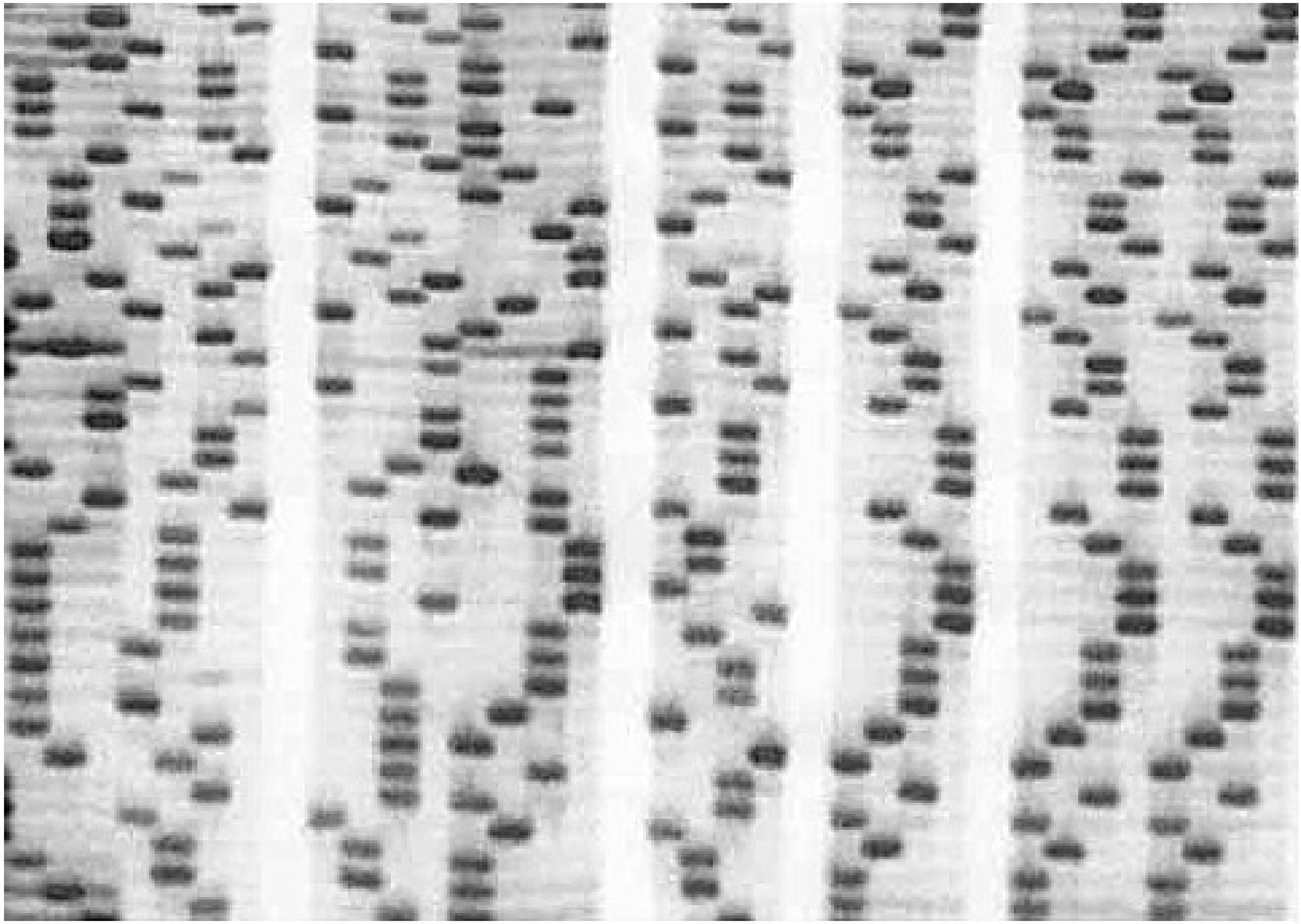
Fig 1. With five orders of linear dynamic range, Storm captures the image from both strong and weak signals in a single exposure. The Storm system's linear dynamic range is 1000 times greater than film.

How storage phosphor works

PhosphorImager



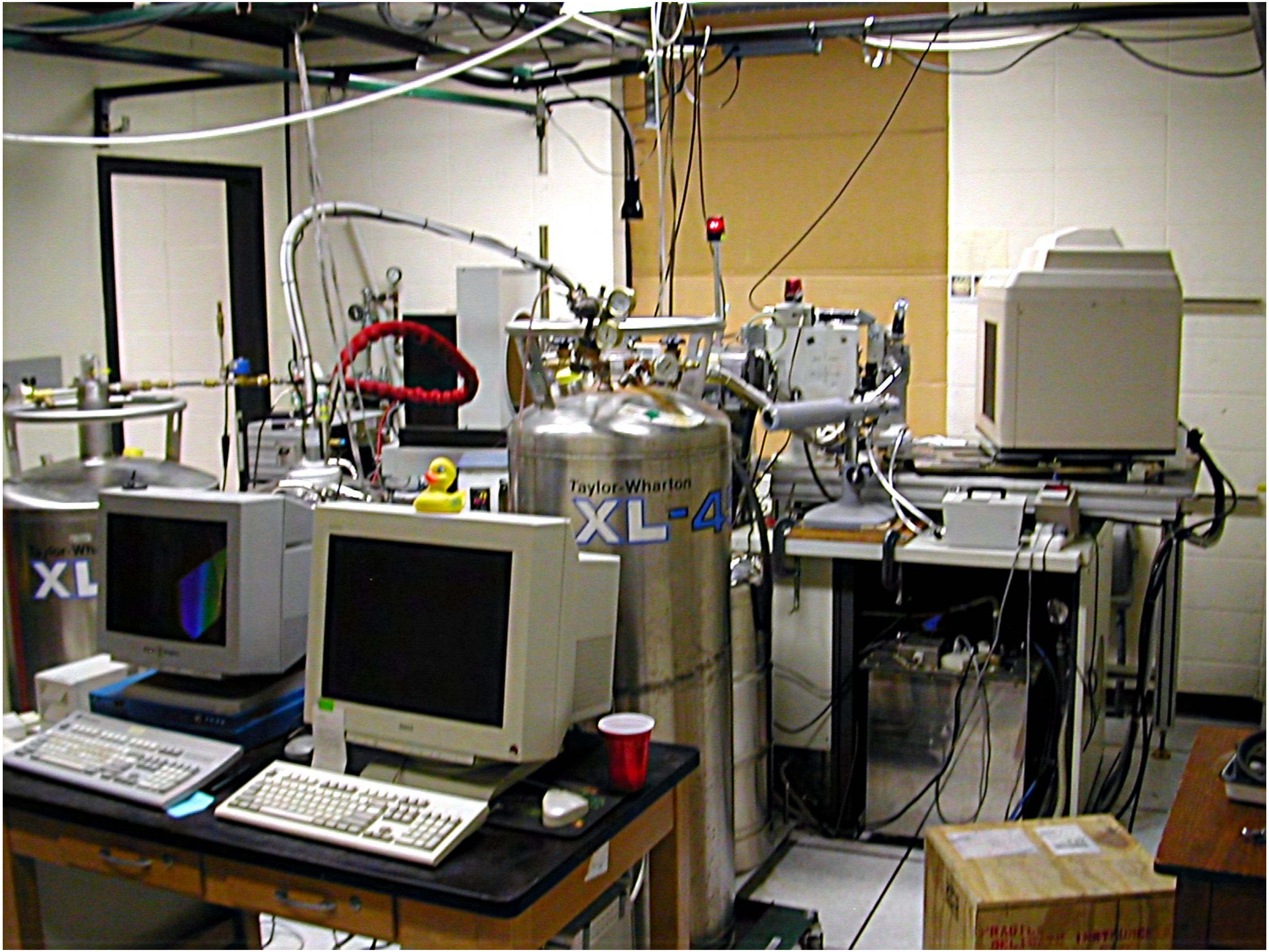
1.Exposure of the storage phosphor screen to ionizing radiation induces latent image formation **2.** During laser scanning, the BaFBR:EU+2 crystals in the screen release energy as blue light **3.** and return to ground state **4.** Blue light is collected and measured to form a quantitative representation of the sample.



DNA Sequencing Gels

DNA Sequencing gels and other large samples fit on the Storm system's 35 x 43 cm scan area. Storm offers the high resolution you need for DNA base identification.

Storm has a 35 x 43 cm (14" x 17") sample area that accepts large samples so you can scan sequencing-sized gels. Or, you can use the large sample area to expose many small gels and blots simultaneously for maximum throughput. Sample exposures take place in cassettes -- not in the instrument -- so the Storm system is always available for scanning. With the Windows NT operating system, scanning can continue even while you're using the same computer to analyze your data and prepare your results for presentation.


Taylor-Wharton
XL-4
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