PUPIL
RESEARCHER
INITIATIVE

# Pupil Research Brief

# PET Scanners

## Setting the Scene

*You will be working as a member of a particle physics department. Your head of department is keen that the department makes a contribution to raising the public understanding of science. He has asked you to design a poster for schools to help inform young people how PET Scanners work, and what they are used for. You also have to produce some questions for pupils to accompany the poster.*

# Study Guide

## Syllabus Targets *Science you will learn about in this Brief*

- ❑ all substances are made of atoms
- ❑ atoms have a small central nucleus, made up of protons and neutrons, around which are the electrons
- ❑ the relative masses and electrical charges of protons, neutrons and electrons
- ❑ all atoms of the same element have the same number of protons
- ❑ the number of protons in a nucleus is called the proton number (or atomic number)
- ❑ the total number of protons and neutrons is called the mass number
- ❑ atoms of the same element can have different numbers of neutrons, these atoms are called isotopes of the element
- ❑ atoms can be represented with their mass number and proton number. For example:

mass number — 23
proton number — 11

$^{23}_{11}Na$ sodium

- ❑ some substances give out radiation all the time and these substances are said to be radioactive
- ❑ there are three types of radiation emitted by radioactive sources
  - alpha ($\alpha$) radiation (helium nuclei - 2 protons and 2 neutrons)
  - beta ($\beta$) radiation (electrons emitted from the nucleus)
  - gamma ($\gamma$) radiation (very short e-m waves)
- ❑ the half-life of a radioactive substance is the time it takes for the number of parent atoms in a sample to halve and the time it takes for the count-rate from the original substance to fall to half the original level
- ❑ you should be able to evaluate the appropriateness of radioactive sources for particular usefulness in terms of the type(s) of radiation emitted and their half lives

## Route through the Brief

**Memo**

**Paper 1** *The clinical uses of PE*

**Paper 2** *The strange world of antimatter*

**Web pages**

**Design of posters**

**Exhibition of posters**

## Outcome Checklist

You will produce a poster for schools with pupil questions on the topic of PET Scanners. A memo guides you through the Brief. You should make sure you produce the following items as you work through the Brief.

**Paper 1**

- ❑ notes on the use of radioactive substances in medicine
- ❑ notes on the medical uses of PET Scanners

**Paper 2**

- ❑ notes on antimatter and radioactive decay by positron emission
- ❑ notes on the creation of anti-hydrogen

**Web pages**

- ❑ drawings and notes explaining how a PET Scanner works

**Poster**

- ❑ notes and design layout including diagrams
- ❑ a set of 5 or 6 questions for pupils

Thomson Institute of Particle Physics
University of West Mercia

# Memo

**From:** Professor Jane Rutherford

**To:** All academic and technical staff

**Date:**

I reported at the last staff meeting that the Research Council had requested that we examine ways we can contribute to the public understanding of science. I have had a suggestion from Sylvia Wright that we do something on the topic of PET Scanners. She feels that this is the key area of our research work and one that is poorly understood by the general public, despite the importance of these machines in hospitals for detecting a range of medical problems. Sylvia has suggested that we target the school audience with a poster entitled *Science in our lives - the PET Scanner*.

I think this is a good idea. Science teachers often put posters on the walls of their classrooms, or on the corridors outside. Teachers also use posters to help them teach some topics, particularly if the poster contains lots of useful information. Some school posters I have seen also have a set of teachers' notes, and even questions and activities for pupils to do, based on using the information on the poster.

Could you have a go at putting together some ideas for a poster design? For this I think you will need to produce a design layout which includes:

- labelled diagrams with short explanatory notes covering uses of PET Scanners and how they work
- brief background information on radiation and antimatter.

You should also produce a separate sheet containing a set of 5 or 6 questions for pupils, to help them use the poster to learn a little about particle physics and how a PET Scanner works.

I have attached 2 pages of information about PET Scanners from a manufacturer's Web site, and two articles from science journals. We need to keep the poster as simple as possible. We can display our finished products, and comment on each other's work, making suggestions for improvements.

I look forward to seeing your efforts.

Best wishes

Jane

# The Clinical Uses of Positron Emission Tomography

This will be useful information for the introduction to the poster

## Introduction

The use of radioactive substances in medicine really started after the Second World War. The earliest techniques used powerful gamma rays to kill off tumours. Later on radioisotopes were used as *tracers* to detect medical problems. Certain substances tend to build up in specific parts of the body. For example, iodine collects in the thyroid gland. So, if a doctor wished to find out if there was something wrong with the thyroid a substance containing radioactive iodine could be given to the patient to swallow, usually as a sodium iodide solution. The amount of radioactive iodine in the thyroid gland can be measured. If this is more or less than that absorbed by a normal, healthy thyroid gland it will indicate whether the thyroid is over- or under-active and needs treatment. People tend to think that gamma rays are more dangerous than other types of radiation. This is not true if the radioactivity is *inside* the body.

| Radiation | If source is outside body | If source is inside body |
|---|---|---|
| alpha | low penetrating power. Radiation is absorbed before it reaches living cells | cells absorb radiation strongly |
| beta | higher penetrating power. Some radiation reaches living cells and may be absorbed | cells absorb radiation weakly |
| gamma | highest penetrating power. Radiation reaches living cells and may be absorbed | cells absorb radiation very weakly |

*Table 1. Penetrating power and absorption levels of $\alpha$, $\beta$ and $\gamma$ radiation by living cells*

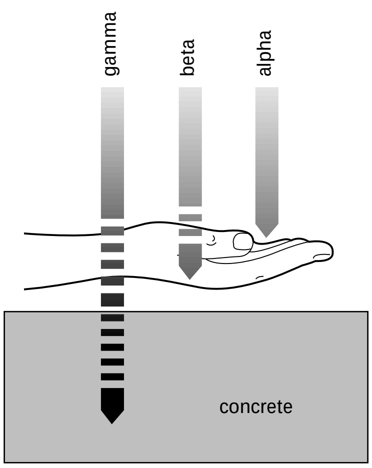



*Figure 1 summarises the penetrating power of the 3 main types of radioactivity from outside the body.*

In 1957 the gamma camera was invented. This is a device that can produce images of parts of the body that have collected substances containing a gamma-emitting radioisotope. So doctors could now see, for instance, arthritic joints in the hand. The radioisotope concentrates in the inflamed parts caused by arthritis.

You will find this helpful information on the uses of PET Scanners, and how they work

## PET Scanners

The 1980s saw the development of Positron Emission Tomography (tomography comes from the Greek word *tomas*, meaning section or slice). This technique uses radioisotopes that emit positrons, which are the same size as electrons but they have a positive charge. When a positron collides with an electron they annihilate and convert their masses into a short but powerful burst of gamma radiation. The gamma rays are sent out in opposite directions. A patient given a positron-emitter lies inside a ring of detectors, which pick up the gamma rays. These detectors produce signals that can be used by a computer to create images.

PET Scanners are very expensive, and they require an equally expensive piece of equipment called a **cyclotron**. This is a particle accelerator that is used for making artificial positron-emitting radioisotopes. Positron-emitters occur in nature, but it is much more convenient to make artificial ones when needed by the hospital.

## Medical Uses

**Figure 2** shows a PET image of a patient with a tumour. Figure 2a is the actual image, and Figure 2b is a line drawing of the same image.

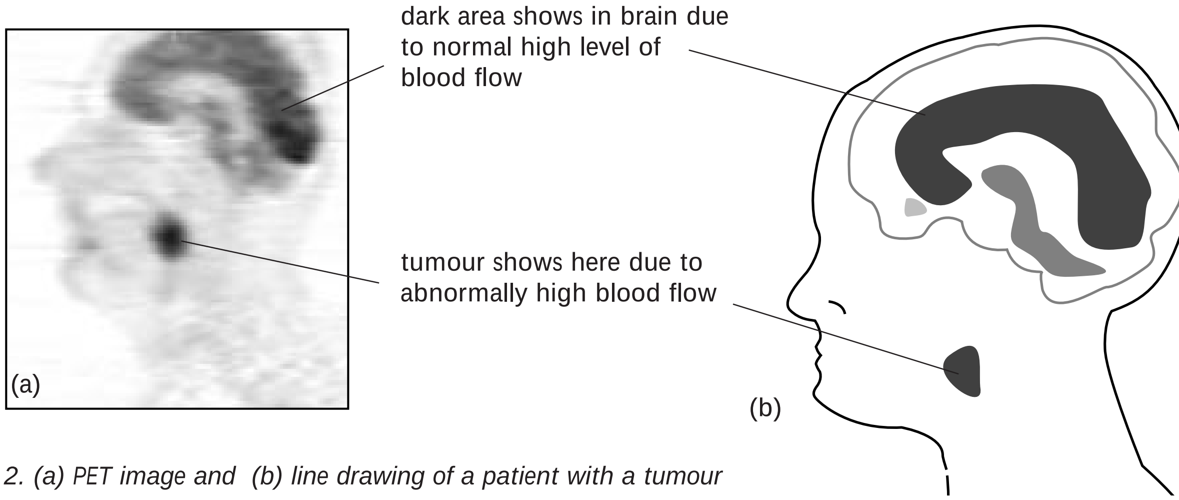



*Figure 2. (a) PET image and (b) line drawing of a patient with a tumour*

Why does the tumour show up so clearly? The patient was injected with glucose which was made radioactive by replacing some of its atoms with positron-emitting atoms. The tumour cells were growing more quickly than normal cells and needed glucose to supply them with energy, and so they emitted most radiation. **Table 2** at the end of this article shows some commonly used positron-emitters and their half-lives. PET Scanners are especially useful in monitoring the progress of medical treatments.

They can be used to pin-point and assess diseases of the brain, such as Alzheimer's, Huntingtons and Parkinson's disease. Within the first few hours of a stroke, PET imaging may be useful in helping the doctor to decide on how to treat the problem.

PET Scanners can differentiate between malignant and benign growths (cancerous and non-cancerous tumours) and they can show up growths as small as 5mm in diameter.

The Scanner is widely used in diagnosing diseases of the heart. PET images can, for instance, help a surgeon to tell if a patient's heart muscle would benefit from coronary artery bypass surgery.

PET Scanners have proved invaluable as a way of helping doctors diagnose diseases and monitor the process of a course of treatment without the need for exploratory operations. Although the combined price of a PET Scanner and a cyclotron is huge, PET Scanners are proving to be very cost-effective.

Glucose was used to send a radioisotope to the tumour shown in Figure 2. Glucose has the chemical formula $C_6H_{12}0_6$. A similar chemical, FDG (fluorodeoxyglucose) could be used in a similar way. This chemical contains fluorine. So a radiologist could choose one of 3 short half-life radioisotopes to produce the PET image.

| **Element** | **Isotope** | **Natural/Artificial (N) (A)** | **Is it a Radioisotope?** | **Radiation Emitted** | **Half life**** |
|---|---|---|---|---|---|
| Hydrogen | $^{1}H$ | N | ✗ | - | - |
| | $^{2}H$ | N | ✗ | - | - |
| | $^{3}H$ | A | ✓ | beta | 12.3 years |
| Carbon | $^{11}C$ | A | ✓ | positron* | 20 minutes |
| | $^{12}C$ | N | ✗ | - | - |
| | $^{13}C$ | N | ✗ | - | - |
| Oxygen | $^{15}O$ | A | ✓ | positron* | 122seconds |
| | $^{16}O$ | N | ✗ | - | - |
| | $^{18}O$ | N | ✗ | - | - |
| Fluorine | $^{18}F$ | A | ✓ | positron* | 2 hours |
| | $^{19}F$ | N | ✗ | | |
| | $^{20}F$ | A | ✓ | beta | 11 seconds |

*Table 2. Isotopes of some common elements*

* a positron and an electron annhilate to produce a pair of gamma rays
** this is the time taken for the number of parent atoms in a sample to halve

# The strange world of antimatter

Antimatter is strange stuff. One way to think of it is that it's like looking at matter in the mirror. You and your reflection in the mirror are basically the same - except right and left are reversed. It's similar with matter and antimatter. An anti-proton is like an ordinary proton except its charge is reversed - instead of having a positive charge it has a negative one (see table below).

You might want to include this table in your poster. Add extra rows to compare an electron with its 'mirror' particle, the anti-electron (positron).

| Particle | Charge | Mass |
|---|---|---|
| Proton | +1 | 1 |
| Anti-proton | - 1 | 1 |

*Table 1. Matter and antimatter*

An English physicist called Paul Dirac predicted the existence of antimatter in the 1930s. Soon after, anti-electrons (usually called positrons) were created in the laboratory, with anti-protons, and anti-neutrons following much later. The latest advance in antimatter research is in creating anti-atoms.

**Annihilation**

The really interesting thing about antimatter is what happens when it meets matter. The two destroy each other in a flash of energy, which appears as gamma rays (See Figure 1). This is a dramatic demonstration of Einstein's famous equation $E=mc^2$ where mass is transformed into pure energy.

You may wish to include this diagram in your poster. You will have to add annotations to help explain what happens when a positron collides with an electron.

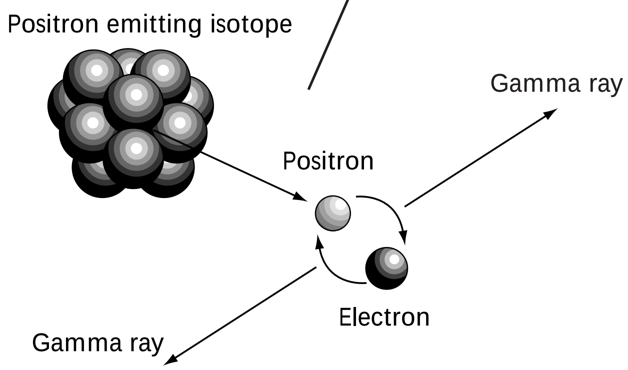



*Figure 1. Matter meets antimatter*

Antimatter doesn't only exist in the laboratory. Some radioactive elements emit positrons naturally and current theories suggest that vast amounts of antimatter were created after the Big Bang. Perhaps there are even whole galaxies made from antimatter. Early next century, the world's first antimatter detector in space will be launched. Let's hope that if there is antimatter out there, it's a long way away.

**Positron emission**

It's a fact of atomic life that some nuclei are less stable than others. The way an unstable nucleus becomes more stable is by throwing out one or more of its particles. This is what we call radioactive decay. Alpha, beta and gamma may be the most familiar types of decay, but many atoms follow a different path towards stability: they emit positrons, which are particles of antimatter.

Here is an example to explain what happens in more detail. Iodine is an element whose atoms come in many varieties, or 'isotopes'. Two isotopes are shown in the table below.

| Isotope | Protons | Electrons | Neutrons |
|---|---|---|---|
| $^{124}I$ | 53 | 53 | 71 |
| $^{127}I$ | 53 | 53 | 74 |

*Table 2. Two isotopes of iodine and the particles they contain*

It is the number of protons in an atom that determines which element it is. You can see that each isotope of iodine contains 53 protons.

The only difference between these isotopes is the number of neutrons in their nucleus. $^{127}I$, the natural form, is stable, but $^{124}I$, which is made artificially, is unstable. What happens is that it transforms one of its protons into a neutron. At the same time, it ejects a positron from the nucleus.

## Creating a new antiworld

Scientists have been making particles of antimatter for 40 years. By accelerating electrons to enormous speed and then smashing them into a material they can cause positrons to appear. Scientists have recently attempted to create whole atoms of antimatter, using very powerful particle accelerators.

The simplest ordinary atom is hydrogen, with a single proton and electron. What scientists at the European Centre for Particle Physics (CERN) have managed to do is to create the world's first atom of anti-hydrogen, by combining an anti-proton with an anti-electron.

The machine used at CERN accelerates a beam of anti-protons through a tube shaped like a running track (see Figure 2). Powerful magnets round the tube give the magnetic field. Once every 'lap' (there are about 3 million laps a second) the beam passes through a jet of xenon gas. Occasionally an anti-proton converts a fraction of its energy into an electron and a positron. Very, very rarely one of the positrons is captured by an anti-proton and an atom of anti-hydrogen is created. During a 3-week period in early 1996 physicists at CERN managed to create nine atoms of anti-hydrogen. Each of these atoms survived for 40 nanoseconds. A nanosecond is one billionth of a second.

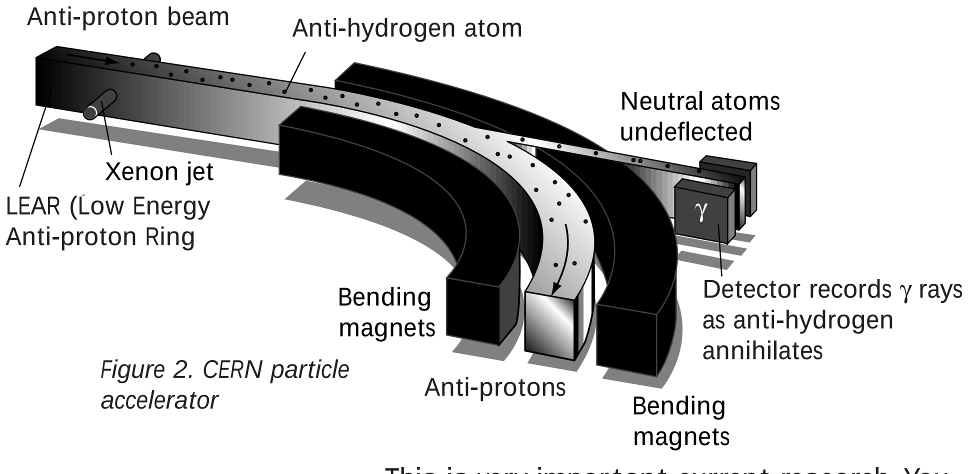



*Figure 2. CERN particle accelerator*

This is very important current research. You need to think about how you present this in your poster. This diagram may help.

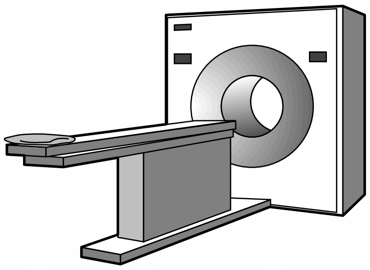
http://www.tomoscan.com/product_info.htm

# The new PET Scanner from TomoScan won't cost you the Earth.

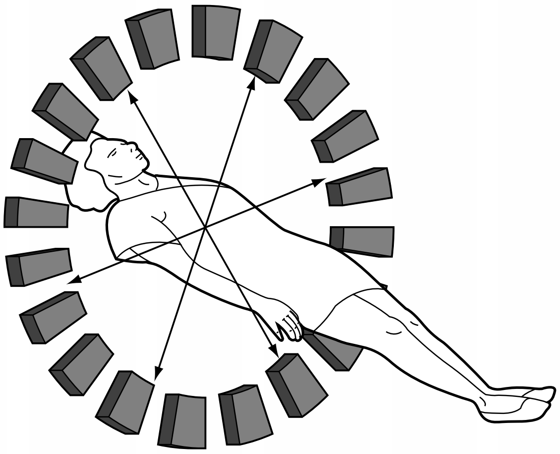
Our new scanner the T036, is our most sophisticated yet. The combination of new gamma ray detectors and more powerful computer imaging make this a most cost effective, high-quality instrument. Our innovative, integrated electronic circuits and ingenious re-design of the ring of detectors have allowed us to combine clinical utility with an economical price.

Also available is our newly - upgraded Cyclotron, the TCT 4. Improved magnet design allows the TCT 4 to produce radiotracers for the TomoScan with improved efficiency and lower cost, while maintaining exceptional levels of performance.

Useful drawings here to include in the poster



The TomoScan TO36



A patient lying inside the ring of detectors

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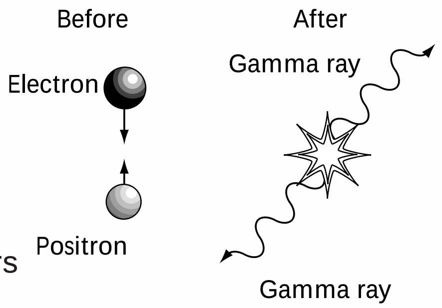
http://www.tomoscan.com/PET_info.htm

# What is PET?

Positron Emission Tomography is a technique that uses special radioactive chemicals to allow doctors to see inside the body. It is different from techniques like X-rays and ultrasound, which let doctors study the structure of the body. PET Scanners can also show *processes* going on in the body, such as metabolic activity or brain functions.
In PET the patient is injected with radiotracers, which contain radioactive substances (radioisotopes) that emit positrons. These radioisotopes have very short half-lives, usually between 75 seconds and 110 minutes. The amount of radiation exposure received by the patient is about the same as from two chest X-rays. The patient lies on a table that slides into the middle of the scanner. Within the scanner are rings of detectors. When a positron is emitted from the radioisotope it travels inside the body no more than 1mm before it meets an electron. An electron and a positron have opposite charges and when they collide they annhilate each other, and create a pair of gamma rays. The detectors contain special crystals that produce a flash of light when struck by a gamma ray. These flashes of light are converted into electronic signals that are sent to the PET Scanner's computer. The computer processes these signals and builds up a picture of the activity going on inside the body. It can also produce images that show slices through the part of the body being studied (this is what 'tomography' means).

Some nice information here on how PET Scanners produce images




When an electron and a positron collide they annhihilate each other and produce a pair of gamma rays

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