Introduction to medical physics II

Dr. Shurooq Saad Mahmood

Lec 1

Radiation therapy

Syllabus

- Application of physics in medicine.
- This survey course will address basic concepts of medical imaging.
- Nuclear medicine and radiation isotopes.
- Radiation therapy.
- Gamma spectroscopy and trace element analysis.
- Biomedical laser application.

Introduction

Radiation therapy is a type of cancer treatment that uses high energy beams to destroy cancer cells and shrink tumors. Radiation therapy most often **uses X-rays**, but **protons** or **other types of energy** also can be used.

- The two main types of **radiation therapy** for treating cancer are external beam radiation and internal radiation therapy.

- The type of radiation that uses will **depend on** the type of cancer, the size and location of the tumor, and the person’s general health.

The term "**radiation therapy**" most often refers to external beam radiation therapy. During this type of radiation, the high-energy beams come from a machine outside of body that aims the beams at a precise point on body. During a different type of radiation treatment called brachytherapy, radiation is placed inside body.

Introduction

Radiation therapy damages cells **by destroying the genetic material DNA** that **controls** how cells grow and divide.

- If the cancer cell cannot repair the DNA, the cell will not be able to produce new cells and may die.
- Both **healthy** and **cancerous cells** are damaged by **radiation therapy**, the goal of radiation therapy is to **destroy as few normal and healthy cells as possible**.
- Normal cells can often repair much of the damage caused by radiation.

More than half of all people with cancer receive radiation therapy as part of their cancer treatment. **Radiation therapy** may help meet different treatment goals. For instance, it may enhance the effectiveness of surgery, help prevent the spread of cancer, or relieve symptoms of advanced cancer.

- Radiation therapy used to treat just about every type of cancer. Its is also useful in treating some noncancerous (benign) tumors.

Cancer

Cancer is a group of diseases involving abnormal cell growth with the potential to invade or spread to other parts of the body. In all types of cancer, some of the body's cells **begin to divide without stopping** and **spread into surrounding tissues**.

Cancer can start almost anywhere in the human body, which is made up of trillions of cells. Normally, **human cells** **grow** and **divide** to **form new cells** as the **body needs them**. When **cells** grow old or become damaged, they **die**, and **new cells** take their place.

When **cancer develops**, however, this **orderly process breaks down**. As cells become more and more abnormal, old or damaged cells survive when they should die, and new cells form when they are not needed.

These **extra cells** can divide without stopping and may form growths called tumors.

Many cancers form **solid tumors**, which are masses of tissue. **Cancers of the blood**, such as **leukemias**, generally do **not form solid tumors**.

Cancer

Cancerous tumors are malignant, which means they **can spread into**, or **invade**, **nearby tissues**. In addition, as these tumors grow, **some cancer cells can break off and travel to distant places in the body** through the **blood** or the **lymph system** and **form new tumors far from the original tumor**.

Unlike malignant tumors, **benign tumors do not spread into**, or **invade**, **nearby tissues**. **Benign tumors** can sometimes be **quite large**, however. **When removed, they usually don’t grow back**, whereas **malignant tumors sometimes do**.

Types of radiation therapy

There are **two** broad types of **radiation therapy** that used to **treat cancers**: **internal** and **external**.

External beam radiation

- External beam radiation is the most common type of radiation treatment for cancer.
- External means that the **energy beams** come from a machine outside of the body. A healthcare **professional precisely aims the beams**, which **penetrate the body** to **reach the cancer site**.
- Another name for external beam radiation is teletherapy.

Types of radiation therapy

There are **two** broad types of **radiation therapy** that used to **treat cancers**: **internal** and **external**.

Internal radiation therapy

The second main type of radiation treatment is internal radiation therapy, also known as **brachytherapy**.

- During this treatment, a **places an implant** containing **radiation** in or near the cancer site.
- The implants come in different shapes, which include:
  - tube.
  - wire.
  - capsule.
  - seeds.
  - pellets.

Types of radiation therapy

There are **two** broad types of **radiation therapy** that used to **treat cancers**: **internal** and **external**.

Internal radiation therapy

- **Systemic radiation therapy:** is another kind of internal radiation therapy.
  - It requires a person to **swallow a radioactive substance**, which **travels throughout the body** to **find** and **kill the cancerous cells**.
  - Alternatively, a healthcare professional may **inject the radioactive substance into a person’s vein**.

How it works

- **External beam radiation** and **brachytherapy** work similarly. Both are local therapies that **work on one part of the body**, **directing high energy beams at cancer cells to destroy them**.

  However, the two therapies **differ** in the **source of the radiation**.

- In **brachytherapy**, the radiation comes from an **implant** that a places near or in a tumor. In **external beam radiation**, the radiation comes from a **machine** outside of the body.

How radiation therapy is used in people with cancer

May suggest **radiation therapy** as an option at different times during your cancer treatment and for different reasons, including:

- As the **only (primary) treatment** for cancer.
- **Before surgery**, to shrink a cancerous tumor (**neoadjuvant therapy**).

After surgery, to stop the growth of any remaining cancer cells (**adjuvant therapy**).

- In combination with other treatments, such as chemotherapy, **to destroy cancer cells**.
- In **advanced cancer** to alleviate symptoms caused by the cancer.

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Radiation therapy

Types of radiation therapy

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- External beam radiation is the most common type of radiation treatment for cancer.
- External means that the **energy beams** come from a machine outside of the body. A healthcare **professional precisely aims the beams**, which **penetrate the body** to **reach the cancer site**. External beam radiotherapy is most commonly delivered using a machine called a ‘linear accelerator’. A picture of a typical linear accelerator is shown below.
- Another name for external beam radiation is teletherapy.

Types of radiation therapy

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Types of radiation therapy

There are **two** broad types of **radiation therapy** that used to **treat cancers**: **internal** and **external**.

Internal radiation therapy (Brachytherapy):

Brachytherapy can be delivered in a couple of different ways. Sometimes a machine called an ‘after-loader’ is used. A number of tubes will be placed in the treatment area. The after-loader is attached to the tubes and the **radioactive source** will travel down the tubes into the treatment area in a very precisely controlled manner. Another way in which Brachytherapy can be delivered is **when small radioactive ‘seeds’ are implanted in the treatment area**.

Types of radiation therapy

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Why is radiotherapy used ?

Radiotherapy treatment may be used for two main purposes:

- to cure the cancer by **destroying** all of the malignant or harmful cells.
- to relieve the symptoms caused by the cancer and to improve the quality of life.

The choice type of radiotherapy treatment **depends** on a number of factors which the radiotherapy team will consider when planning treatment:

- The type of cancer.
- The size of the tumor.
- The tumor’s location in the body.
- How close the tumor is to normal tissues that are sensitive to radiation.
- Your general health and medical history.
- Whether you will have other types of cancer treatment.
- Other factors, such as your age and other medical conditions.

How radiation therapy is used in people with cancer

May suggest **radiation therapy** as an option at different times during your cancer treatment and for different reasons, including:

- As the **only (primary) treatment** for cancer.
- **Before surgery**, to shrink a cancerous tumor (**neoadjuvant therapy**).

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- In combination with other treatments, such as chemotherapy, **to destroy cancer cells**.
- In **advanced cancer** to alleviate symptoms caused by the cancer.

Risks

Radiation therapy side effects **depend** on which part of body is being exposed to radiation and how much radiation is used. may experience no side effects, or may experience several. Most side effects are temporary, can be controlled and generally disappear over time **once treatment has ended**.

Part of body being treated	Common side effects
Any part	Hair loss at treatment site (sometimes permanent), skin irritation at treatment site, fatigue.
Head and neck	Dry mouth, thickened saliva, difficulty swallowing, sore throat, changes in the way food tastes, nausea, mouth sores, tooth decay.
Chest	Difficulty swallowing, cough, shortness of breath.
Abdomen	Nausea, vomiting, diarrhea.
Pelvis	Diarrhea, bladder irritation, frequent urination, sexual dysfunction.

Risks

Some side effects may **develop later**. For example, in rare circumstances a new cancer (second primary cancer) that's different from the first one **treated with radiation** may develop years later.

What is radiation?

Radiation is simply the **transfer of energy from one place to another**. Radiation is all around us, for instance, light, radio waves and microwaves are all forms of radiation. We give the different types of radiation different names depending on how much energy the radiation is transferring. Some radiation is harmful to humans and some is not. **Radiotherapy** uses a type of radiation that transfers enough energy to damage harmful cells in the human body.

What is radiation?

The **radiation** used in radiotherapy can be produced in different ways, for example:

- In a machine called a 'linear accelerator', particles called '**electrons**' are accelerated to high speed towards a metal target. When they hit the target they have to slow down very quickly and this forces them to release energy in the form of radiation. Magnets and shielding blocks are used to direct the radiation to the right place.

- The radiation can come from a 'radioactive material' this is a material which has excess energy. The material naturally loses this energy over time by releasing radiation.

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Radiation therapy

Sources of Ionizing Radiation

- **Photons:**
  - **Gamma Rays**
    - **Emitted from a nucleus of a radioactive atom.**
      - **Cobalt treatment machine.**
      - **Radioisotopes used in brachytherapy.**
  - **X-rays**
    - **Generated by a linear accelerator when accelerated electrons hit a target.**
- **Particle Beams:**
  - **Protons**
  - **Neutrons**
  - **Electrons**

* **Most <u>external beam radiation treatments</u> use <u>photons generated</u> by a linear accelerator.**

What is the Biologic Basis for Radiation Therapy?

Radiation therapy works by damaging the DNA of cells and destroys their ability to reproduce.

High-energy radiation mostly harms cells by **damaging the DNA molecules** in some way. This does not necessarily mean immediate apoptosis (*cell death*) but **functioning DNA is central to successful cell replication** and **tissue growth**. Unrepaired damage to DNA hinders cell replication and eventually prevents further cell growth.

The harmful potential of high-energy photons relies on their energy greatly exceeding that of typical chemical bonds in organic molecules (these chemical bonds are made up by **pairs of tightly connected electrons**).

What is the Biologic Basis for Radiation Therapy?

The direct process shown in Figure (1) is the **main mechanism to damage DNA molecules**: a direct effect, simply breaking chemical bonds in the DNA strands.

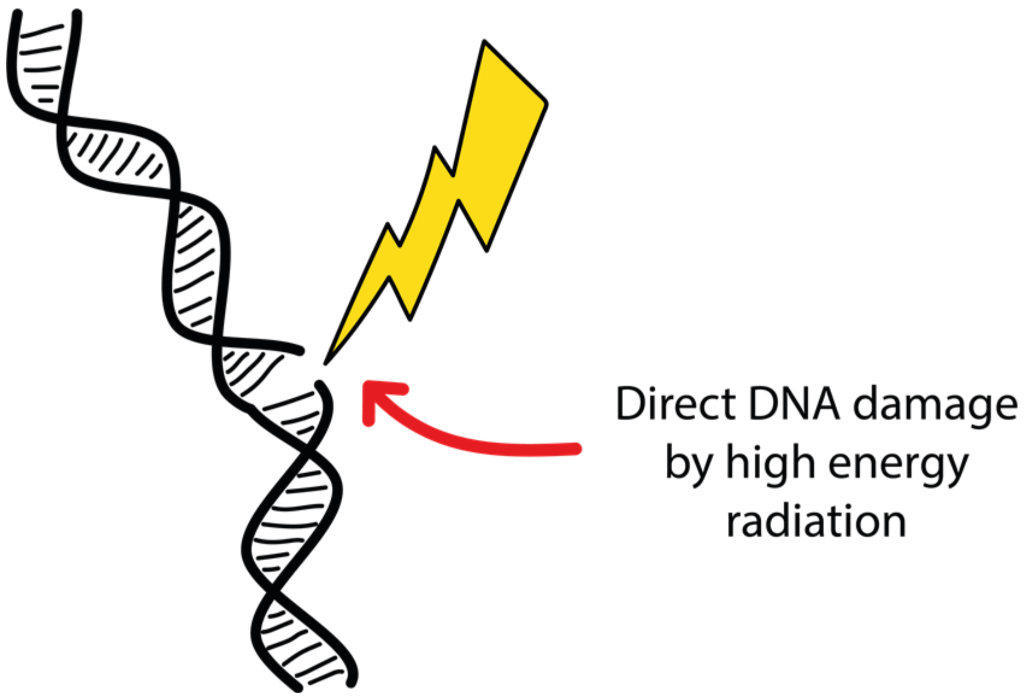


Figure 1: Direct damage to DNA molecules caused by high-energy radiation.

What is the Biologic Basis for Radiation Therapy?

Both **normal** and **cancer cells** can be affected by radiation, but cancer cells have generally impaired ability to repair this damage, leading to **cell death**.

All tissues have a tolerance level, or maximum dose, beyond which irreparable damage may occur.

How radiation affects cells?

The primary way radiation affects our health is through breakage of DNA molecules. DNA consists of two long chains of nucleotides twisted together into a double helix; it is the molecular compound in the nucleus of a cell that forms the blueprint for the structure and function of the cell. Radiation is able to break these chains. When it does, **three things can happen:**

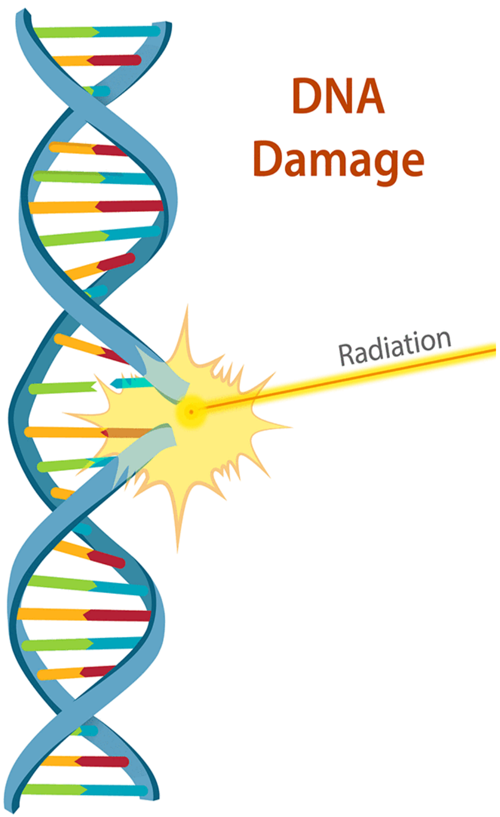


Figure 2: This image shows a beam of radiation breaking the double helix of a DNA strand resulting in DNA damage.

What is the Biologic Basis for Radiation Therapy?

1) The DNA is repaired properly

In this case, the cell is repaired properly and it continues to function normally. **DNA breakage occurs normally every second of the day** and **cells have a natural ability to repair that damage**.

2) The DNA damage is so severe that the cell dies (deterministic effects)

When the DNA or other critical parts of a cell **receive** a **very high dose of radiation**, normally **delivered over a short period of time**, the cell may either die or be damaged beyond repair. If this kills a large enough number of cells in a tissue or organ, early radiation effects may occur. These are called **deterministic effects** and the severity of the effects varies according to the radiation dose received. They can **include** **acute radiation syndrome**, **skin burns**, **loss of hair**, and in extreme cases, **death**. Most deterministic effects occur shortly after exposure and above dose thresholds specific to each exposed tissue. The pattern of the symptoms for most of the effects **is so specific** that trained medical professionals can **diagnose a deterministic effect of radiation**.

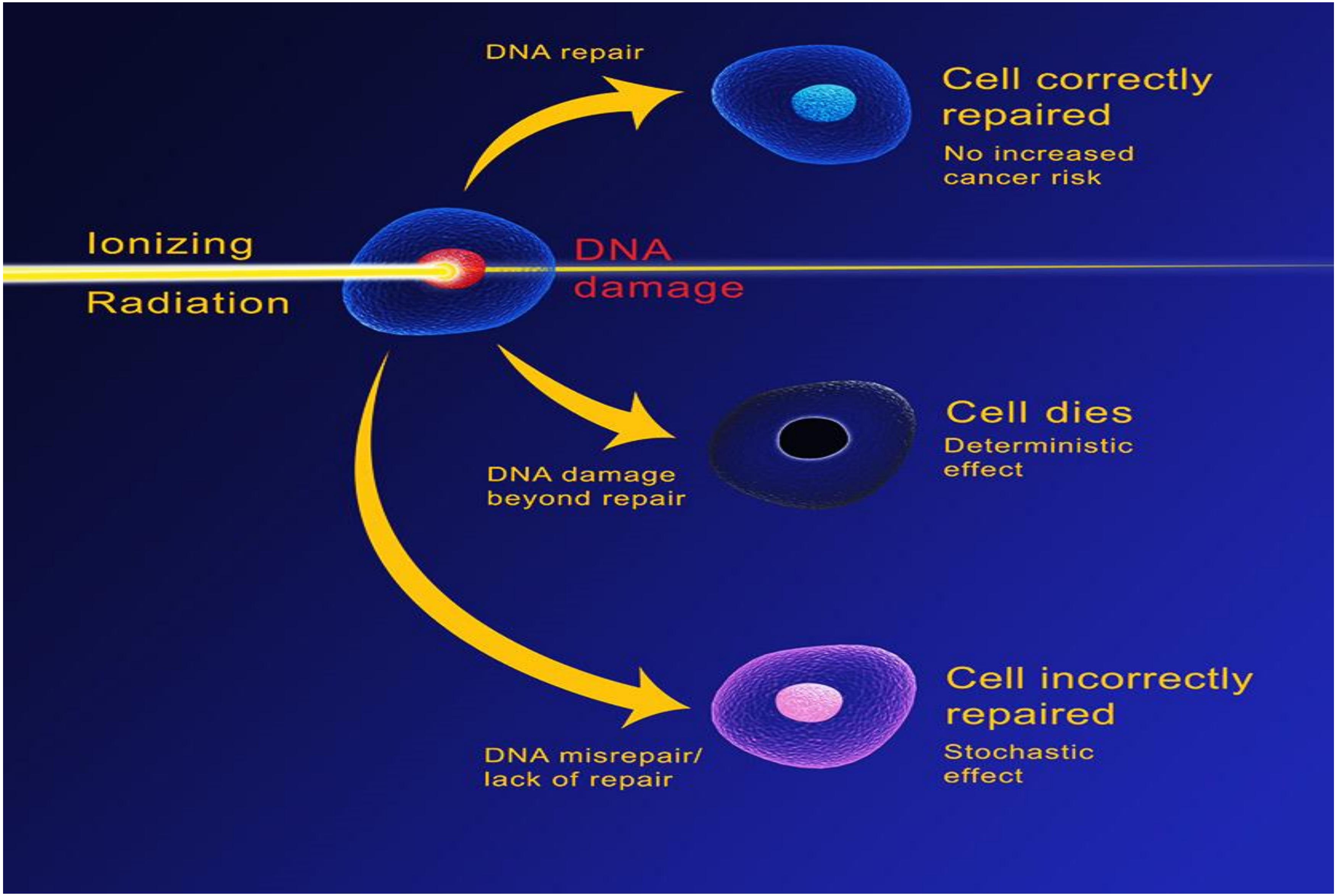


Figure 3: This image shows what may occur after ionizing radiation causes DNA damage. The DNA can either repair correctly, DNA damage can be beyond repair and result in cell death (**deterministic effect**), or DNA can repair itself incorrectly (**stochastic effect**).

What is the Biologic Basis for Radiation Therapy?

3) The cell incorrectly repairs itself, but it continues to live (stochastic effects)

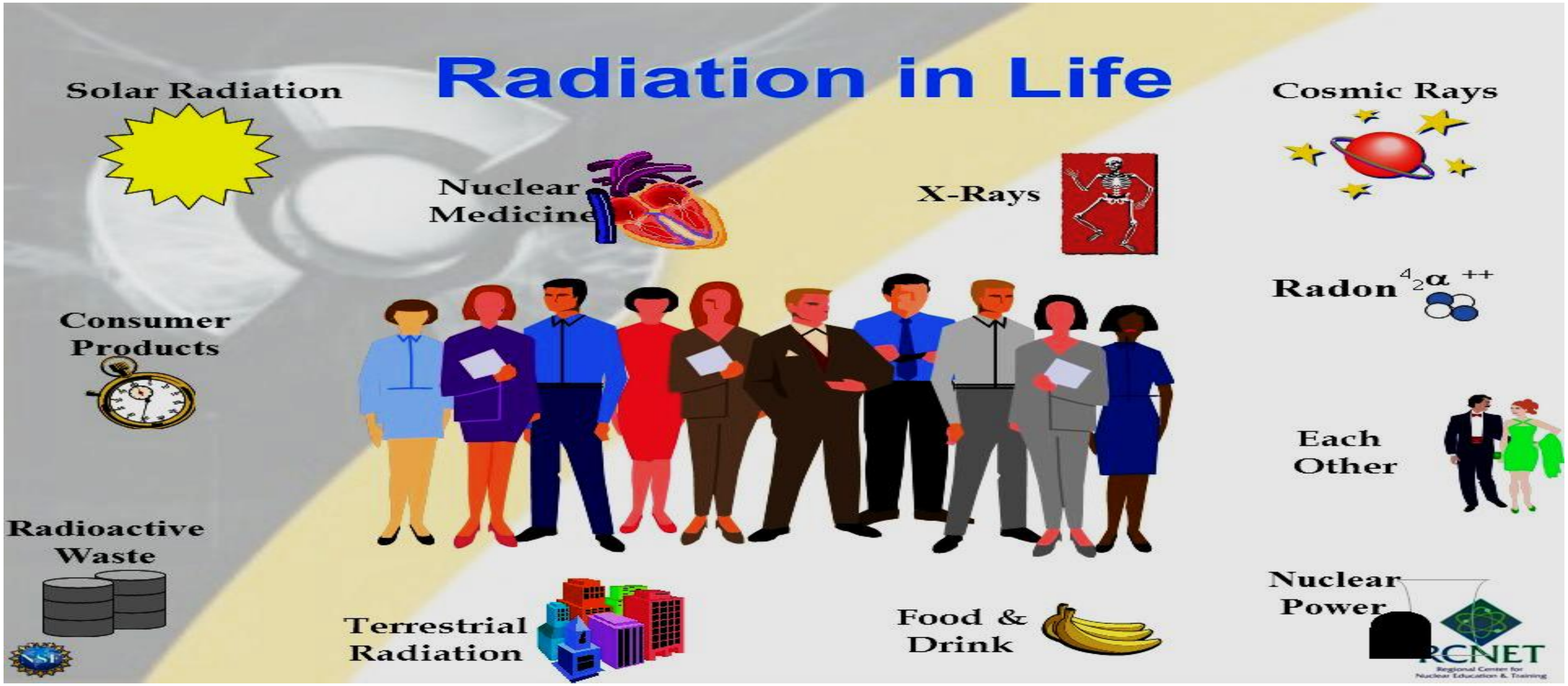
In some cases, the DNA of the cell may be damaged by radiation, but the **damage does not kill the cell**. The cell may continue to live and even reproduce itself, but the cell and its descendents may no longer function properly and may disrupt the function of other cells.

The probability of this type of detrimental effect is **proportionate** to the dose and it is called a stochastic effect – when there is a statistical probability that the effects of exposure will occur.

In such cases, the likelihood of the effects **increases** as the **dose increases**. However, the timing of the effects or their severity does **not depend on the dose**.

What is the Biologic Basis for Radiation Therapy?

This process happens all the time in everyone. In fact, people are exposed to about 15,000 such events every second of every day. Sometimes**, the cell structure changes because it repairs itself improperly**. **This alteration** could have no further effect, or the effect could show up later in life. Cancer and hereditary effects may or may not take place.



Radiation Therapy Dosage

When **radiation therapy** is <u>used to kill cancerous cells</u> in the body, it <u>is important to measure the dose correctly</u> **to avoid unnecessary damage to normal cells in the body**.

Radiation is not selective to tumor cells and therefore <u>targets any cells that are in the process of replication</u> when the <u>therapy is applied</u>. This thereby stresses **the importance of administering the correct dose** in order to ensure optimal efficiency with minimal side effects.

Standard dose

Gray (Gy) is the **unit used to measure the total amount of radiation** that the patient is exposed to. This can also be recorded as **centigray (cGy)**, which is:

1Gy = 100 centigray (cGy)

Radiation Therapy Dosage

Standard dose

Therapy doses typically range from 45 to 60 Gy for the treatment of breast, head, and neck cancers. Typically, these doses are divided into multiple smaller doses that are given over a period of one to two months. The **specific dose** for each patient **depends** on the location and severity of the tumor. The dose determination is therefore at the discretion of the radiation oncologist who is responsible for such therapeutic decisions.

Techniques and types of External Beam Radiation Therapy (EBRT)

External beam radiation therapy (EBRT) is the most common form of radiation therapy. **Beams of high-energy radiation are directed at the tumor**. The position of the machine *can be changed* to aim the beams at different angles.

EBRT is given via machines called linear accelerators, which produce high-energy external radiation beams that penetrate the tissues and deliver the radiation dose deep in the areas where the cancer resides. These modern machines and other state-of-the-art techniques have enabled radiation oncologists to significantly reduce side effects while improving the ability to deliver radiation.

Techniques and types of External Beam Radiation Therapy (EBRT)

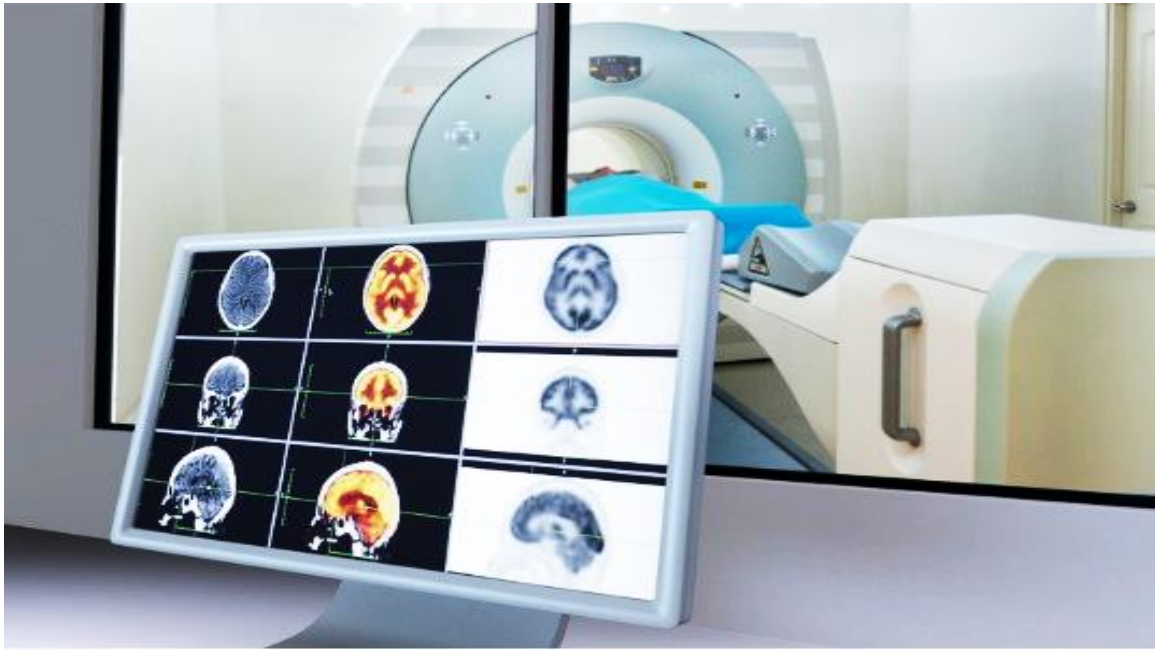
Types of external radiotherapy include:

- **Three-dimensional conformal radiation therapy (3DCRT)**
- **Intensity-modulated radiation therapy (IMRT)**
- **Image-guided radiation therapy (IGRT)**
- **Stereotactic radiosurgery (SRS) and stereotactic radiation therapy (SRT)**
- **Stereotactic body radiation therapy (SBRT)**
- **Proton therapy**

Techniques and types of External Beam Radiation Therapy (EBRT)

Three-dimensional conformal radiation therapy (3DCRT)

3D conformal radiation therapy: **Computed tomography (CT) scans** and special computer software help **create a three-dimensional computer model** of the area to be treated. Treatments are <u>more precisely targeted to the tumor</u>, <u>sparing surrounding normal tissue</u>. Used to treat **many different types of cancer**.



Techniques and types of External Beam Radiation Therapy (EBRT)

Intensity Modulated Radiation Therapy (IMRT)

IMRT is an advanced form of **3-D conformal radiation therapy** that allows doctors to customize the radiation dose by modulating, or varying, the amount of radiation given to different parts of the area being treated. The radiation intensity is adjusted with the use of computer-controlled, moveable "leaves" which either block or allow the passage of radiation from the many beams that are aimed at the treatment area. The leaves are carefully adjusted according to the shape, size, and location of the tumor. As a result, more radiation can be delivered to the tumor cells while less is directed at the normal cells that are nearby.

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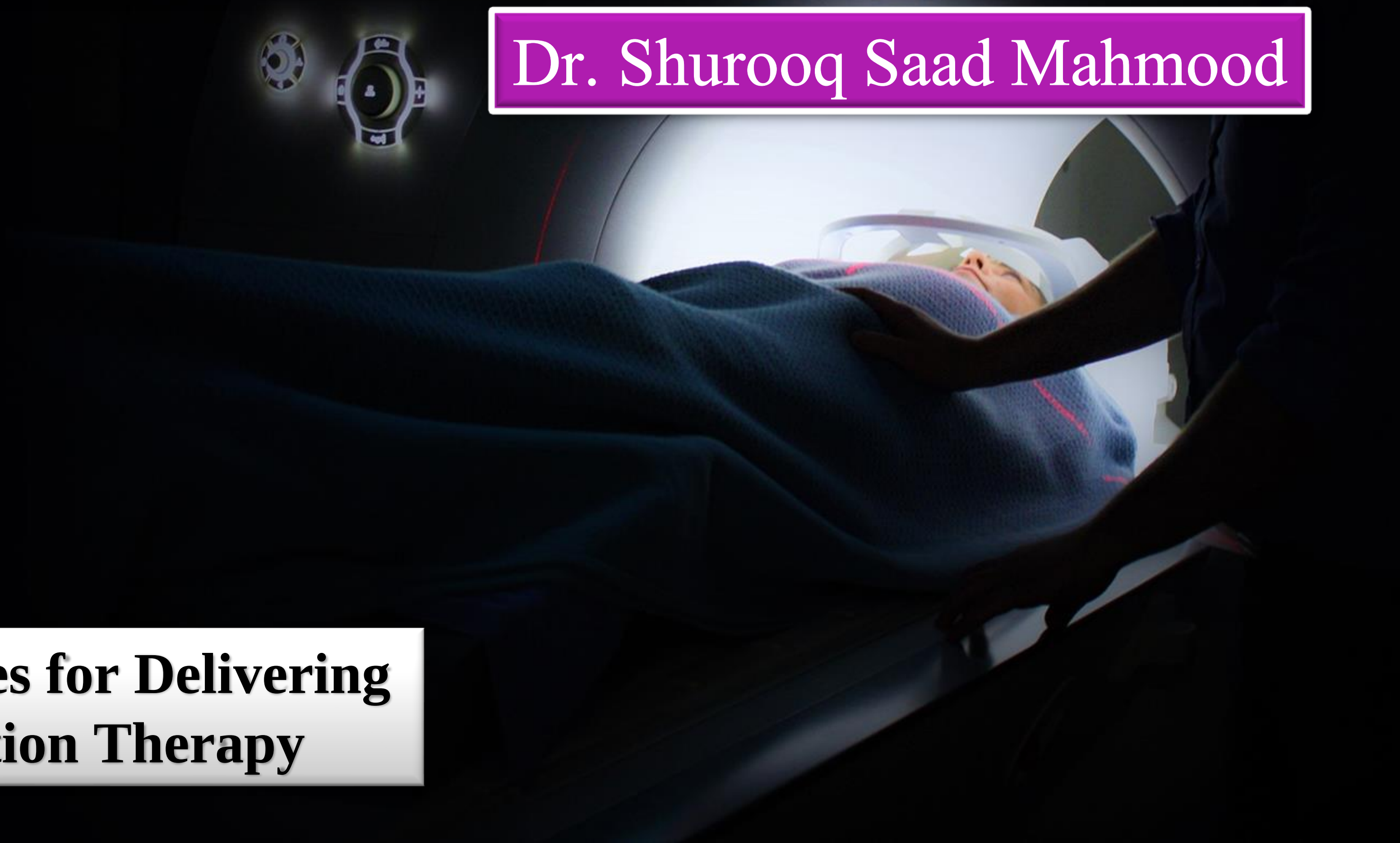

Techniques for Delivering Radiation Therapy

Techniques for Delivering Radiation Therapy

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Techniques for Delivering Radiation Therapy

Three-dimensional conformal radiation therapy (3DCRT)

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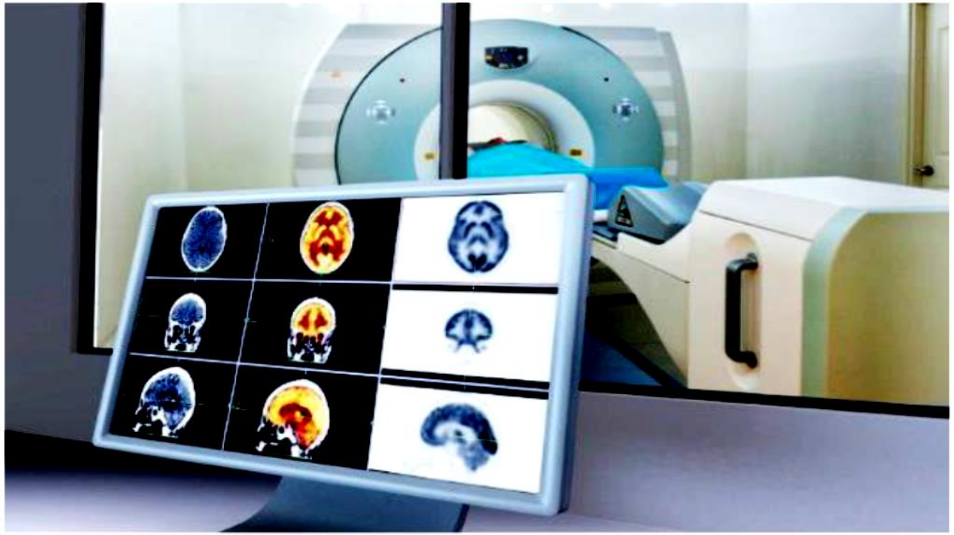

Techniques for Delivering Radiation Therapy

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Techniques for Delivering Radiation Therapy

Image-guided Radiation Therapy (IGRT)

Image-guided radiation therapy (IGRT) is a method of radiation therapy that incorporates **imaging techniques during each treatment session**.

Radiation therapy uses high-energy beams of radiation to control cancer and noncancerous tumors. By adding detailed images, IGRT ensures the powerful radiation is narrowly focused at the treatment area.

When undergoing IGRT, high-quality images are taken before each radiation therapy treatment session. IGRT may make it possible to use higher doses of radiation, which increases the probability of tumor control and typically results in shorter treatment schedules.

IGRT is the standard of care for radiation therapy treatment. It's used to treat all types of cancer.

IGRT is used in conjunction with EBRT, 3D-CRT or IMRT.

Techniques for Delivering Radiation Therapy

Image-guided Radiation Therapy (IGRT)

Why it's done?

IGRT is used to treat all types of cancer, **but** it's particularly ideal for tumors and cancers located very close to sensitive structures and organs. IGRT is also useful for tumors that are likely to move during treatment or between treatments.

IGRT is used as part of radiation treatment plans because it offers:

- Accurate delivery of radiation.
- Improved definition, localization and monitoring of tumor position, size and shape before and during treatment.
- The possibility of higher, targeted radiation dosage to improve tumor control.
- Decreased radiation exposure to normal tissue surrounding the tumor.

Techniques for Delivering Radiation Therapy

Stereotactic radiosurgery (SRS)

Stereotactic radiosurgery (SRS) uses many precisely focused radiation beams to treat tumors and other problems in the **brain**, **neck**, **lungs**, **liver**, **spine and other parts of the body**.

It is not surgery in the traditional sense because there's no incision. Instead, stereotactic radiosurgery uses 3D imaging to target high doses of radiation to the affected area with minimal impact on the surrounding healthy tissue.

Like other forms of radiation, stereotactic radiosurgery works by damaging the DNA of the targeted cells. The affected cells then lose the ability to reproduce, which causes tumors to shrink.

Techniques for Delivering Radiation Therapy

Stereotactic radiosurgery (SRS)

Stereotactic radiosurgery of the brain and spine is typically completed in a single session. Body radiosurgery is used to treat lung, liver, adrenal and other soft tissue tumors, and treatment typically involves multiple (three to five) sessions.

Doctors use three types of technology to deliver radiation during stereotactic radiosurgery in the brain and other parts of the body:

- **Linear accelerator (LINAC) machines** use X-rays (photons) to treat cancerous and noncancerous abnormalities in the brain and other parts of the body. **LINAC machines** are also known by the brand name of the manufacturer, such as CyberKnife and TrueBeam. These machines can perform stereotactic radiosurgery (SRS) in a single session or over three to five sessions for larger tumors, which is called fractionated stereotactic radiotherapy.

Techniques for Delivering Radiation Therapy

Stereotactic radiosurgery (SRS)

Doctors use three types of technology to deliver radiation during stereotactic radiosurgery in the brain and other parts of the body:

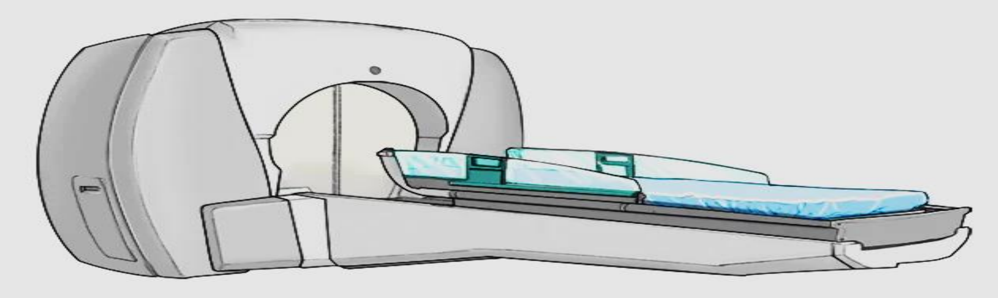
- **Gamma Knife machines** use 192 or 201 small beams of gamma rays to target and treat cancerous and noncancerous brain abnormalities. Gamma Knife machines are less common than LINAC machines and are used primarily for small to medium tumors and lesions in the brain associated with a variety of conditions.
- **Proton beam therapy** (charged particle radiosurgery) is the newest type of stereotactic radiosurgery and is available in only a few research centers in the U.S, although the number of centers offering proton beam therapy has greatly increased in the last few years. Proton beam therapy can treat brain cancers in a single session using stereotactic radiosurgery, or it can use fractionated stereotactic radiotherapy to treat body tumors over several sessions.

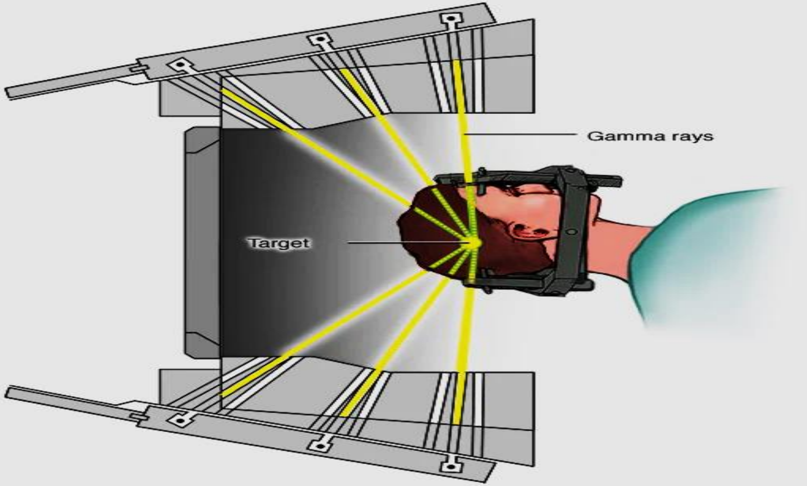
Techniques for Delivering Radiation Therapy

Stereotactic radiosurgery (SRS)

Gamma Knife stereotactic radiosurgery

Gamma Knife stereotactic radiosurgery technology uses many small gamma rays to deliver a precise dose of radiation to a target.





Gamma Knife unit and radiation delivery

Techniques for Delivering Radiation Therapy

Stereotactic body radiation therapy (SBRT)

When doctors use stereotactic radiosurgery to treat tumors in areas of the body other than the brain, it's sometimes called stereotactic body radiotherapy (SBRT) or stereotactic ablative radiotherapy (SABR).

The procedure uses many precisely focused radiation beams to treat tumors and other problems all over the body.

Because there's no incision, SBRT isn't a traditional type of surgery. Instead, SBRT uses 3D imaging to target high doses of radiation to the affected area. This means there's very little damage to the surrounding healthy tissue. Like other forms of radiation, stereotactic radiosurgery works by damaging the DNA of the targeted cells. Then, the affected cells can't reproduce, which causes tumors to shrink.

Body radiotherapy usually involves between one to five sessions.

Techniques for Delivering Radiation Therapy

Stereotactic radiosurgery (SRS) and Stereotactic body radiation therapy (SBRT)

How it works?

All types of stereotactic radiosurgery and radiotherapy work in a similar manner.

The specialized equipment focuses beams of radiation on a tumor or other target. Each beam has very little effect on the tissue it passes through, but a targeted dose of radiation is delivered to the site where all the beams intersect.

The high dose of radiation delivered to the affected area causes tumors to shrink and blood vessels to close off over time following treatment, robbing the tumor of its blood supply.

The precision of stereotactic radiosurgery means there's minimal damage to the healthy surrounding tissues. In most cases, radiotherapy has a lower risk of side effects compared with other types of traditional surgery or radiation therapy.

Techniques for Delivering Radiation Therapy

Stereotactic radiosurgery (SRS) and Stereotactic body radiation therapy (SBRT)

Why it's done?

Around 50 years ago, **stereotactic radiosurgery** was pioneered as a less invasive and safer alternative to standard brain surgery (neurosurgery), which requires incisions in the skin, skull, membranes surrounding the brain and brain tissue.

Since then, the use of SRS has expanded widely to treat a variety of neurological and other conditions. SBRT may be used to treat cancers of the **liver, lung, abdomen, lymph nodes and spine**.

Techniques for Delivering Radiation Therapy

Proton therapy

Proton therapy is a type of radiation therapy — a treatment that uses high-energy beams to treat tumors. Radiation therapy using X-rays has long been used to treat cancers and noncancerous (benign) tumors. **Proton therapy** is a **newer type of radiation therapy that uses energy from positively charged particles called protons**.

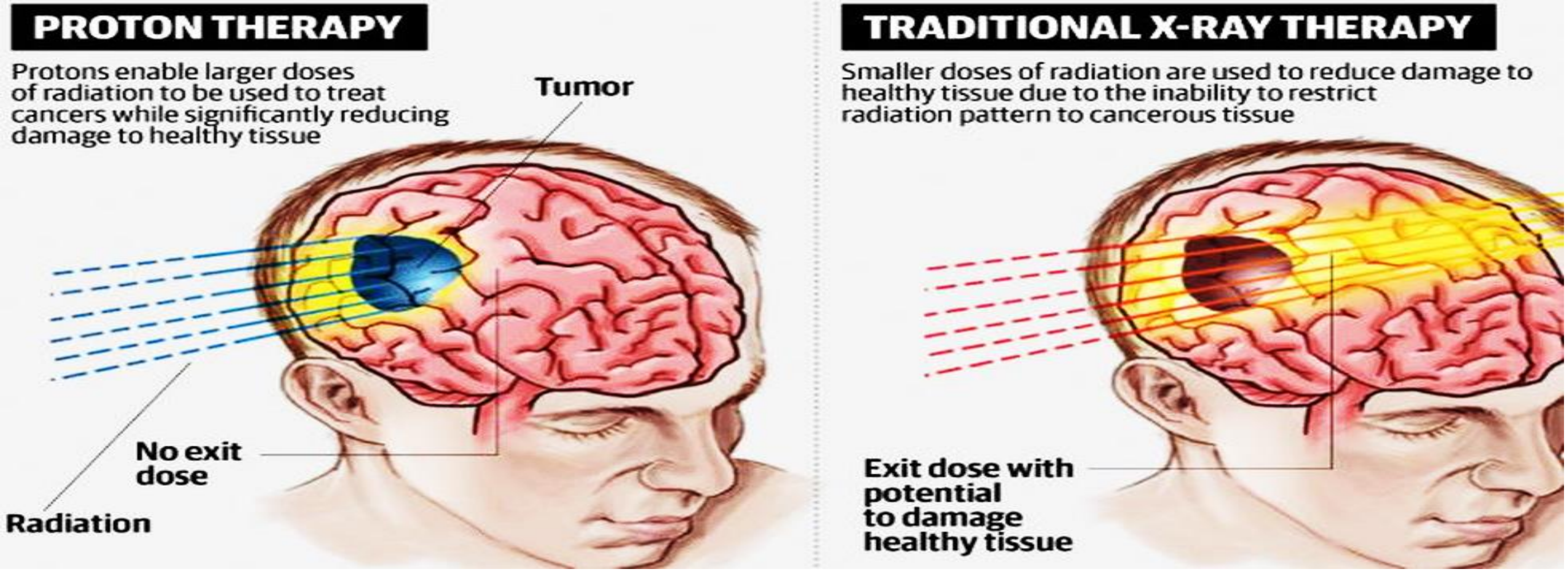
- Protons are tiny parts of atoms with a positive charge that release most of their radiation within the cancer.

Proton therapy has shown promise in treating several kinds of cancer. Studies have suggested that proton therapy may cause fewer side effects than traditional radiation, since doctors can better control where the proton beams deposit their energy. But few studies have directly compared proton therapy radiation and X-ray radiation, so it's not clear whether proton therapy is more effective in prolonging lives.

Techniques for Delivering Radiation Therapy

Proton therapy

- Proton therapy is useful when the cancer is near sensitive areas, such as the brainstem or spinal cord, especially in children.
- Special machines called cyclotrons and synchrotrons are used to **generate and deliver the protons**.



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Gamma Spectroscopy

Radioactivity

Radioactivity is the property of some unstable atoms (**radionuclides**) to spontaneously emit nuclear radiation, usually alpha particles or beta particles often accompanied by gamma-rays.

This radiation is emitted when the nucleus undergoes radioactive decay and is converted into a different isotope which may, **according to its number of neutrons and protons**, be either **radioactive** (**unstable**) or **non-radioactive** (**stable**).

This "daughter" nucleus will usually be of a different chemical element to the original isotope.

What causes atoms to be radioactive?

Atoms found in nature are either **stable** or **unstable**. An **atom is stable** if the forces among the particles that makeup the nucleus are balanced. An **atom is unstable (radioactive)** if these forces are unbalanced; if the **nucleus has an excess of internal energy**.

Instability of an atom's nucleus may result from an excess of either neutrons or protons. A radioactive atom will attempt to reach stability by ejecting nucleons (protons or neutrons), as well as other particles, or by releasing energy in other forms.

Nuclides with lower neutron/proton ratios tend to undergo positron emission, electron capture, or alpha emission, whereas nuclides with higher neutron/proton ratios tend to undergo beta emission.

What happens to atoms after they release radiation?

As the nucleus emits radiation or disintegrates, the **radioactive atom (radionuclide)** transforms to a **different nuclide**.

This process is called **radioactive decay**. It will continue until the forces in the nucleus are balanced.

For example, as a radionuclide decays, it will become **a different isotope of the same element** if it gives off neutrons or a **different element altogether** if it gives off protons.

Radioactive Decay

The elements can exist in numerous states which are not stable. For example, a nucleus can **have too many neutrons for the number of protons it has** or contrarily, it can **have too few neutrons for the number of protons it has**.

Alternatively, the nuclei can exist in an excited state, wherein a nucleon is present in an energy state that is higher than the ground state.

In all of these cases, **the unstable state is at a higher energy state** and **the nucleus must undergo some kind of decay process** to reduce that energy.

There are many types of radioactive decay, but type most relevant to gamma-ray spectroscopy is **gamma decay**.

In γ decay, the **excited nucleon decays to a lower energy state** and the **energy difference is emitted as a quantized photon**. The photon emitted from a nuclear transition is known as a γ-ray.

What are gamma rays?

A gamma ray (γ-ray) is a packet of electromagnetic energy (**photon**) emitted by the nucleus of some **radionuclides** following **radioactive decay**.

<u>**Gamma photons**</u> are **the most energetic photons** in the electromagnetic spectrum.

What are the properties of gamma rays?

Gamma rays are a form of electromagnetic radiation (EMR). They are the similar to X-rays, distinguished only by the fact that they are emitted from an excited nucleus.

Electromagnetic radiation can be described in terms of **a stream of photons**, which are massless particles each travelling in a wave-like pattern and moving at the speed of light.

Each photon contains a certain amount (or bundle) of energy, and all electromagnetic radiation consists of these photons.

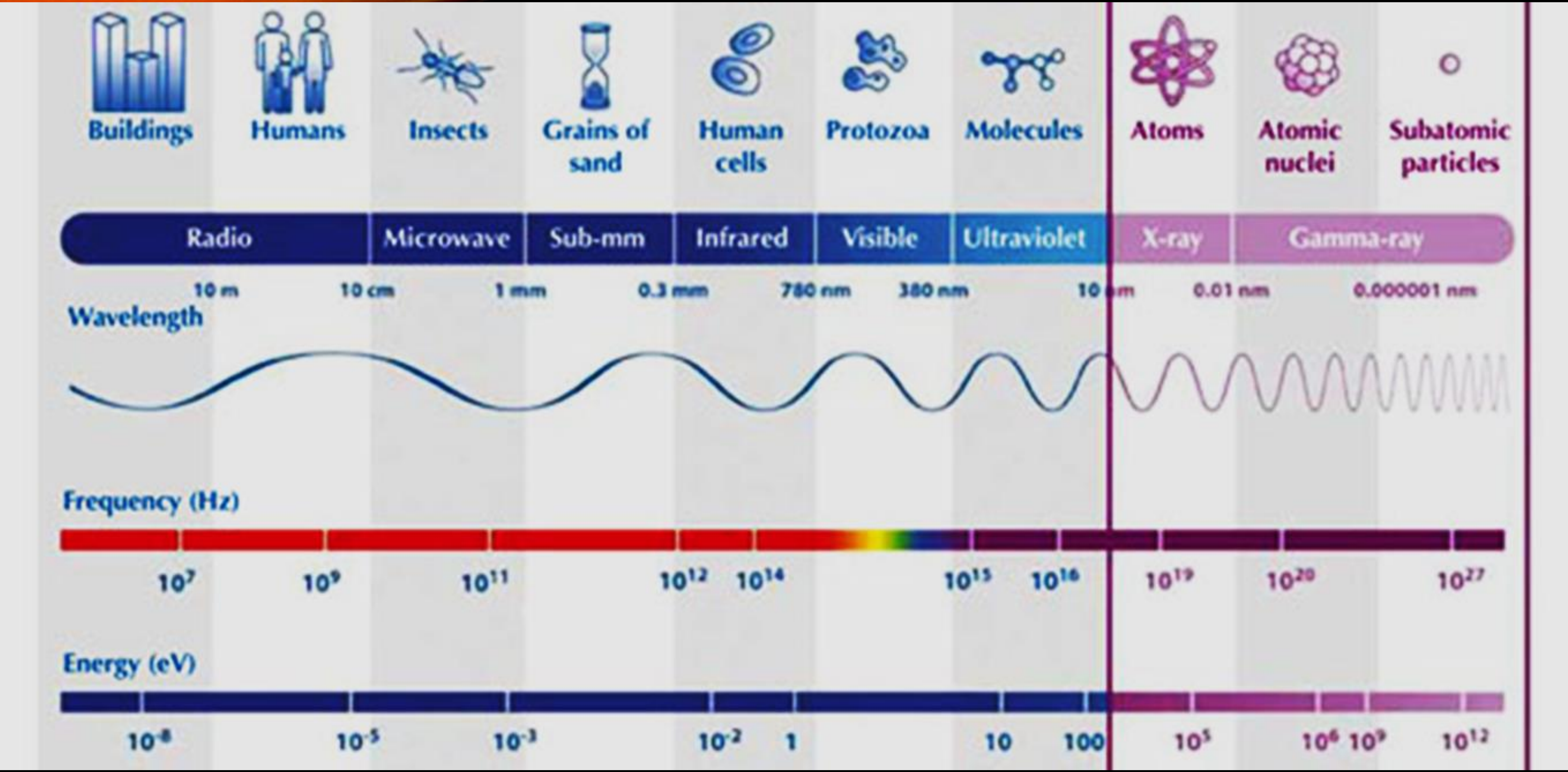
Gamma-ray photons have the highest energy in the EMR spectrum and their waves have the shortest wavelength.

What are the properties of gamma rays?

Scientists measure the energy of photons in electron volts (eV).

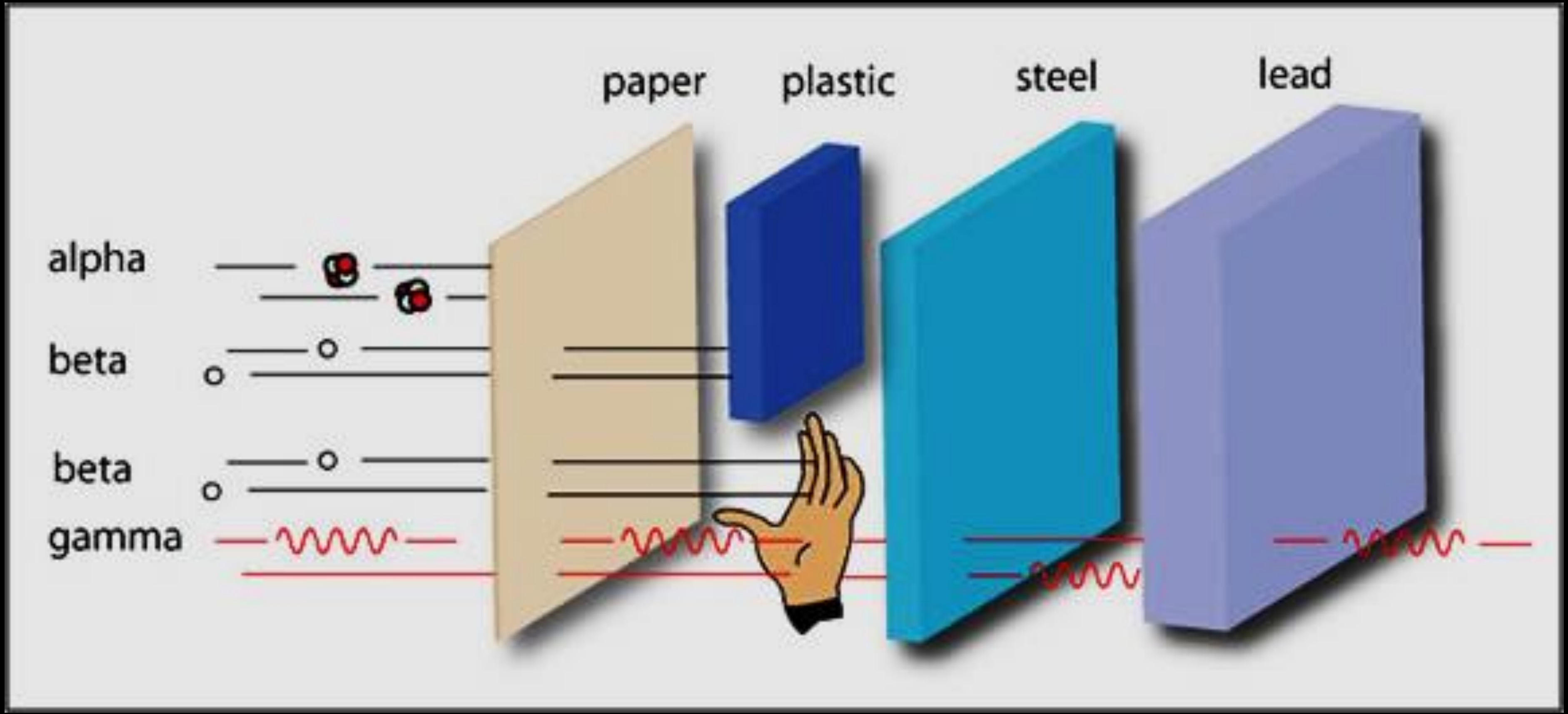
- X-ray photons have energies in the range 100 eV to 100,000 eV (or 100 keV).
- Gamma-ray photons generally have energies greater than 100 keV.

For comparison, **ultraviolet radiation** has energy that falls in the range from a few electron volts to about 100 eV and does not have enough energy to be classified as **ionizing radiation**.



- High frequency >10^{19} Hz; high energies >100KeV and short wavelengths <10 picometers
- (1 Picometer (pm) = 0.001 Nanometer(nm)).

The **high energy of gamma rays** enables them to pass through many kinds of materials, **including human tissue**. **Very dense materials**, such as **lead**, are commonly used **as shielding to slow or stop gamma rays**.



What is the difference between gamma rays and X-rays?

The key difference between gamma rays and X-rays is **how they are produced**.

Gamma rays originate from the settling process of an excited nucleus of a radionuclide after it undergoes radioactive decay.

Whereas **X-rays** are produced when electrons strike a target or when electrons rearrange within an atom.

Cosmic rays also **include high-energy photons** and these are also called **gamma-rays** whether or not they originated from nuclear decay or reaction.

What are the health effects of exposure to gamma radiation?

Due to their high penetration power, the impact of gamma radiation can occur throughout a body.

Similar to all exposure to ionizing radiation, high exposures can cause direct acute effects through immediate damage to cells. Low levels of exposure carry a stochastic health risk where the probability of cancer induction rises with increased exposure.

Exposure to high doses of radiation over a short period of time can cause radiation sickness (sometimes called radiation poisoning or acute radiation syndrome) and even death.

Some of the symptoms of radiation sickness include fainting, confusion, nausea and vomiting, diarrhea, hair loss, skin and mouth sores, and bleeding.

What are some common sources of gamma radiation?

Gamma radiation is released from many of the radioisotopes found in the natural radiation decay series of uranium, thorium and actinium as well as being emitted by the naturally occurring radioisotopes potassium-40 and **carbon-14**. These are found in all rocks and soil and even in our food and water.

Artificial sources of gamma radiation are produced in fission in nuclear reactors, high energy physics experiments, nuclear explosions and accidents.

Introduction to medical physics II

Lec 6

Dr. Shurooq Saad Mahmood

Gamma Spectroscopy

Gamma ray detectors

The **detection** and **measurement** of gamma rays has so many applications because there are countless different sources that produce gamma rays. Gamma rays are emitted in nuclear processes during radioactive decay or in nuclear reactions. When a nucleus in excited energy level, goes back to ground level, it releases energy in form of gamma rays.

Gamma ray detectors measure electromagnetic radiation through the process of the counting and measuring the energy of individual photons emitted from elements. The **measured energy of a gamma ray** corresponds to the type of element and its isotope, while **the number of counts** corresponds to the abundance of the radioactive source.

Gamma ray detectors

Different types of detectors are used for detecting gamma rays. One common method is called **scintillation**, which involves turning the energy of the gamma ray into visible light. The other common method, used by **solid state semiconductors**, creates electron/hole pairs that converts the energy of gamma rays into electricity.

High purity germanium detectors stand out as the most commonly used solid state detector material when high energy-resolution is needed.

Gamma ray detectors

The kinds of detectors commonly used can be categorized as:

1. Scintillation Detectors
2. Semiconductor Detectors
3. Gas-filled Detectors

The choice of a particular detector type for an application depends upon the gamma energy range of interest and the application's resolution and efficiency requirements. Additional considerations include count rate performance, the suitability of the detector for timing experiments, and of course, price.

Gamma ray detectors

Detector Efficiency

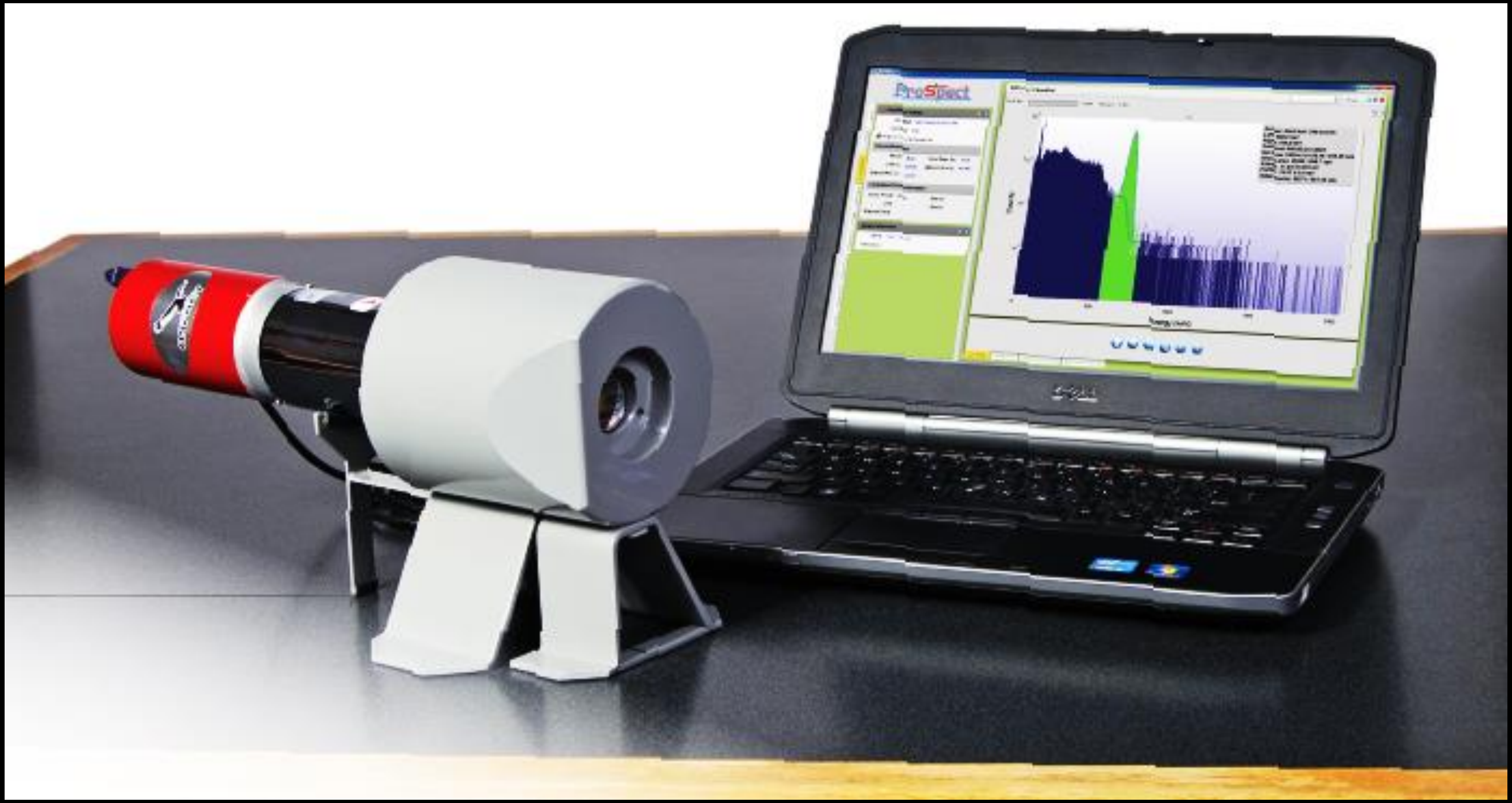
The efficiency of a detector is a measure of how many pulses occur for a given number of gamma rays. Various kinds of efficiency definitions are in common use for gamma ray detectors:

1. Absolute Efficiency: The ratio of the number of counts produced by the detector to the number of gamma rays emitted by the source (in all directions).
2. Intrinsic Efficiency: The ratio of the number of pulses produced by the detector to the number of gamma rays striking the detector.
3. Relative Efficiency: Efficiency of one detector relative to another.
4. Full-Energy Peak (or Photopeak) Efficiency: The efficiency for producing full-energy peak pulses only, rather than a pulse of any size for the gamma ray.

Clearly, to be useful, the detector must be capable of absorbing a large fraction of the gamma ray energy. This is accomplished by using a detector of suitable size, or by choosing a detector material of suitable high Z.

Gamma ray detectors

Scintillation Detector



Gamma ray detectors

Scintillation Detector

A scintillation detector is one of several possible methods for detecting ionizing radiation.

Scintillation is the process by which some material, be it a solid, liquid, or gas, emits light in response to incident ionizing radiation.

The properties of scintillation material required for good detectors are transparency, availability in large size, and large light output proportional to gamma ray energy. Relatively few materials have good properties for detectors. Thallium activated NaI and CsI crystals are commonly used, as well as a wide variety of plastics.

NaI is still the dominant material for gamma detection because it provides good gamma ray resolution and is economical.

In practice, this is used in the form of a **single crystal of sodium iodide** that is **doped** with a **small amount of thallium**.

Gamma ray detectors

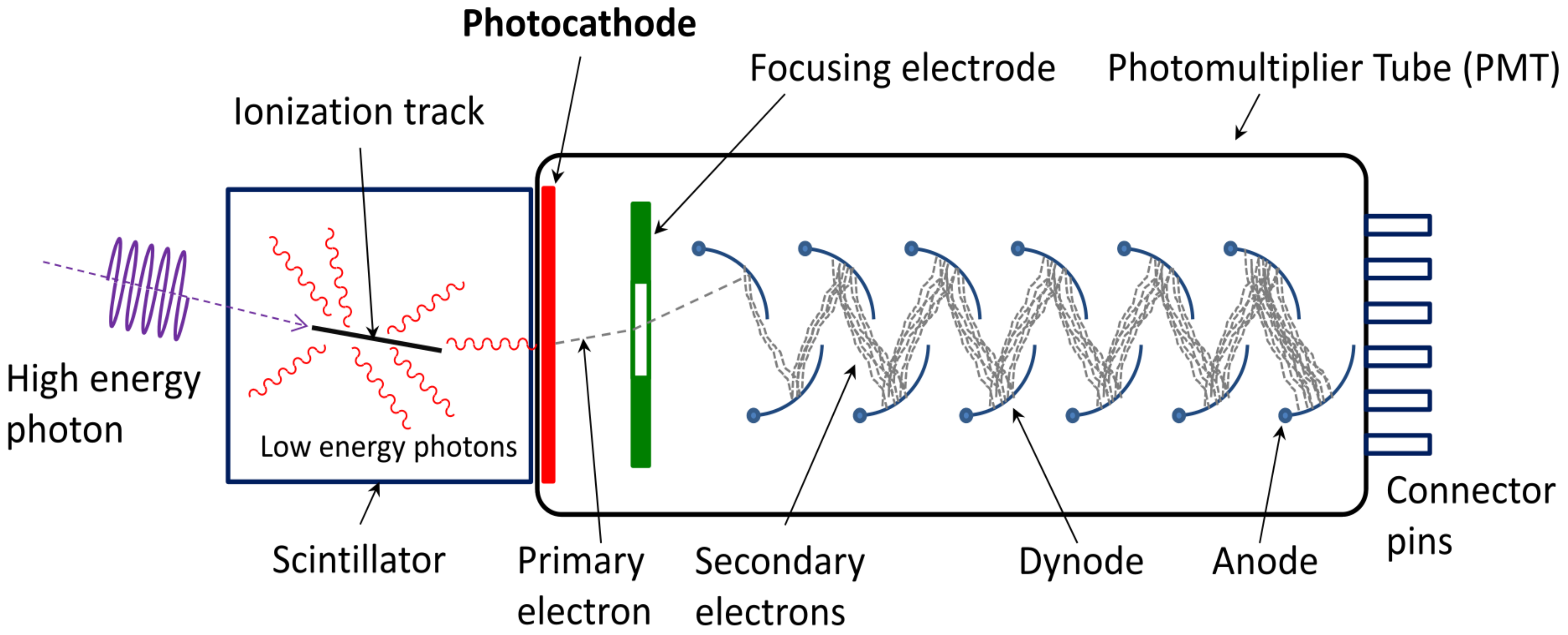
Scintillation Detector

The high Z of iodine in NaI gives **good efficiency for gamma ray detection**. A small amount of Tl is added in order to **activate the crystal**, so that the designation is usually NaI(Tl) for the crystal.

This crystal is **coupled to a photomultiplier tube** which converts the small flash of light into an electrical signal through the photoelectric effect. This electrical signal can then be detected by a computer.

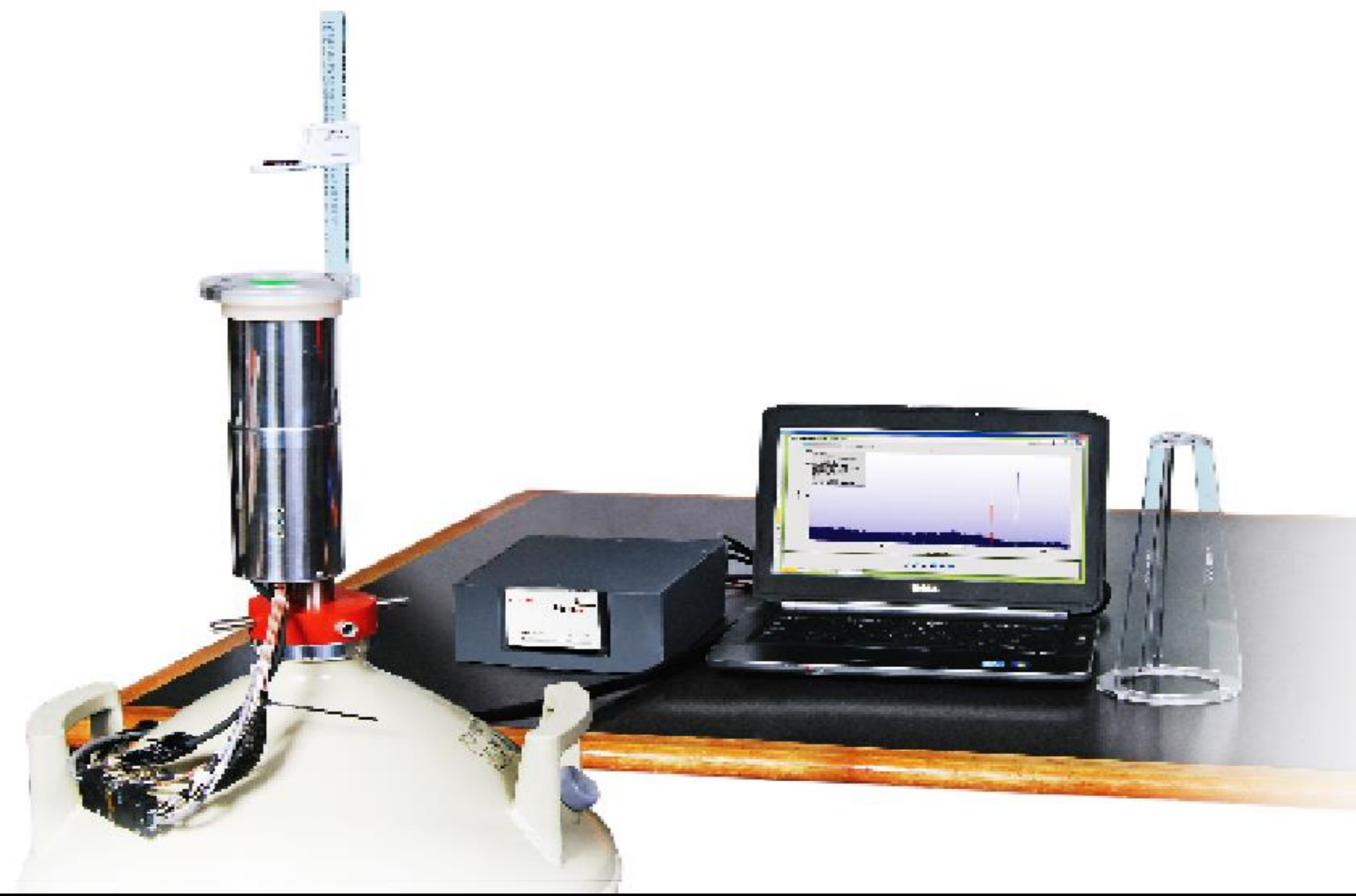
A gamma ray **interacting** with a scintillator produces a pulse of light, which is converted to an electric pulse by a photomultiplier tube.

The photomultiplier consists of a photocathode, a focusing electrode and 10 or more dynodes that multiply the number of electrons striking them several times each. The anode and dynodes are biased by a chain of resistors typically located in a plug-on tube base assembly.


Photocathode
Focusing electrode
Photomultiplier Tube (PMT)
Ionization track
High energy photon
Low energy photons
Connector pins
Scintillator
Primary electron
Secondary electrons
Dynode
Anode

Gamma ray detectors

Semiconductor Detector



Gamma ray detectors

Semiconductor Detector

The use of semiconductor detectors for gamma-ray detection has provided tremendous gains **in measurement capability**. The gamma-ray peaks obtained with NaI detectors are very broad by comparison, so that two peaks close to each other cannot be resolved and low- energy peaks may not be easily observed. **Semiconductor detectors made of germanium or silicon compensated with lithium provide significantly better energy resolution**.

A semiconductor is a material that can act as an insulator or as a conductor. In electronics the term “solid state” is often used interchangeably with semiconductor, but in the **detector field the term can obviously be applied to solid scintillators**. Therefore, semiconductor is the preferred term for those detectors which are fabricated from either elemental or compound single crystal materials having a band gap in the range of approximately 1 to 5 eV.

Gamma ray detectors

Semiconductor Detector

In insulators, the band gap between the valence band (fully occupied) and conduction band (completely empty) is high, and **no electric field or temperature rise can provide enough energy for electrons in the valence band to cross the gap and reach the conduction band** (Figure 1). However in semiconductors the band gap is small, and **increased temperature, incident charged particles, or applied electric field can impart enough energy to electrons to move them from the valence band to the conduction band**.

When an electron moves from the valence band to the conduction band, a hole is created in its place in the valence band. Holes behave like particles with positive charge, and they contribute to the overall conductivity of the semiconductor.

Gamma ray detectors

Semiconductor Detector

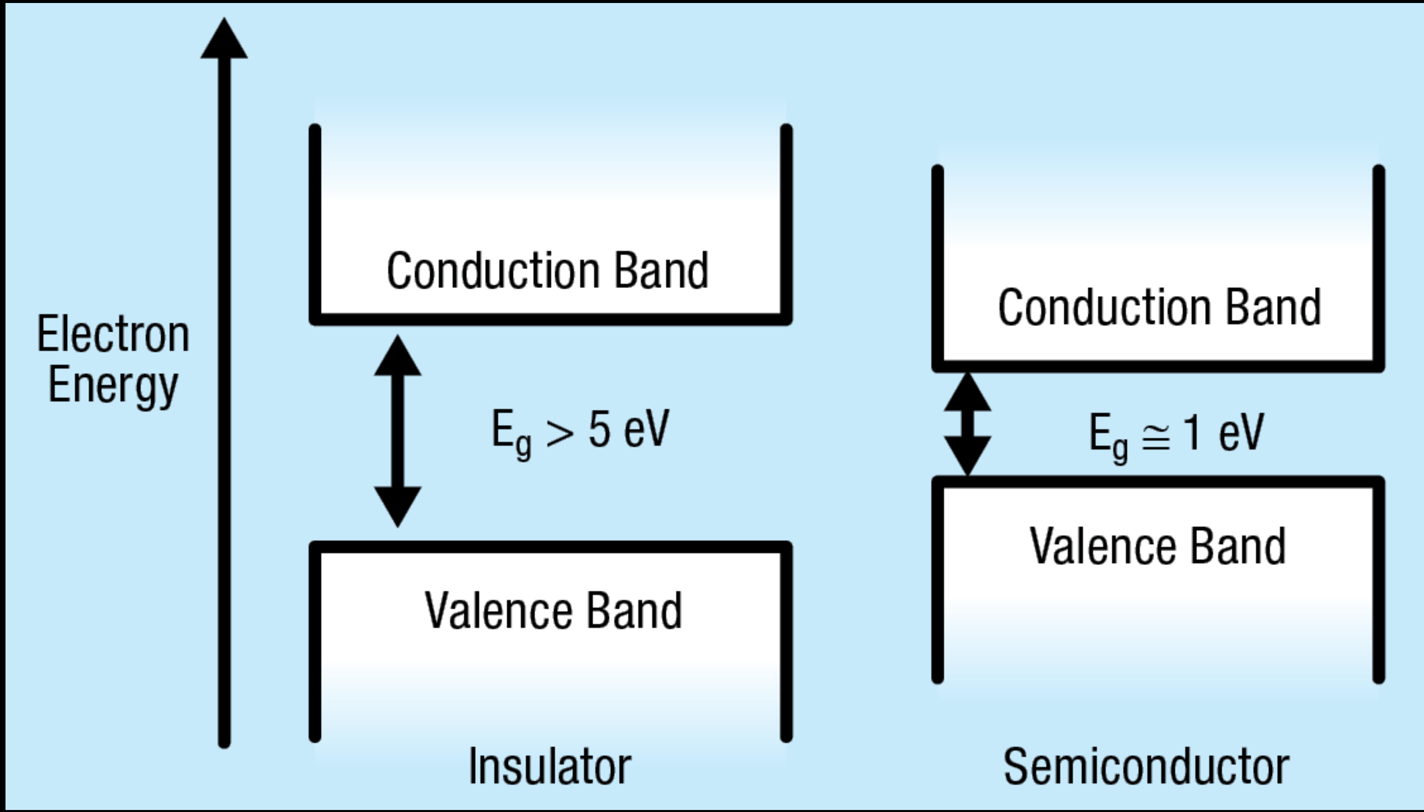


Figure 1: Band structure in insulators and semiconductors. E_g is the band gap energy.

Gamma ray detectors

Semiconductor Detector

A semiconductor accomplishes the same effect as a scintillation detector, conversion of gamma radiation into electrical pulses, except through a different route.

In a **semiconductor**, there is a small energy gap between the valence band of electrons and the conduction band.

When a semiconductor is hit with gamma-rays, the energy imparted by the gamma-ray is enough to promote electrons to the conduction band. This **change in conductivity can be detected** and a signal can be generated correspondingly.

Germanium crystals doped with lithium, Ge(Li), and high-purity germanium (HPGe) detectors are among the most common types.

Gamma ray detectors

Semiconductor Detector

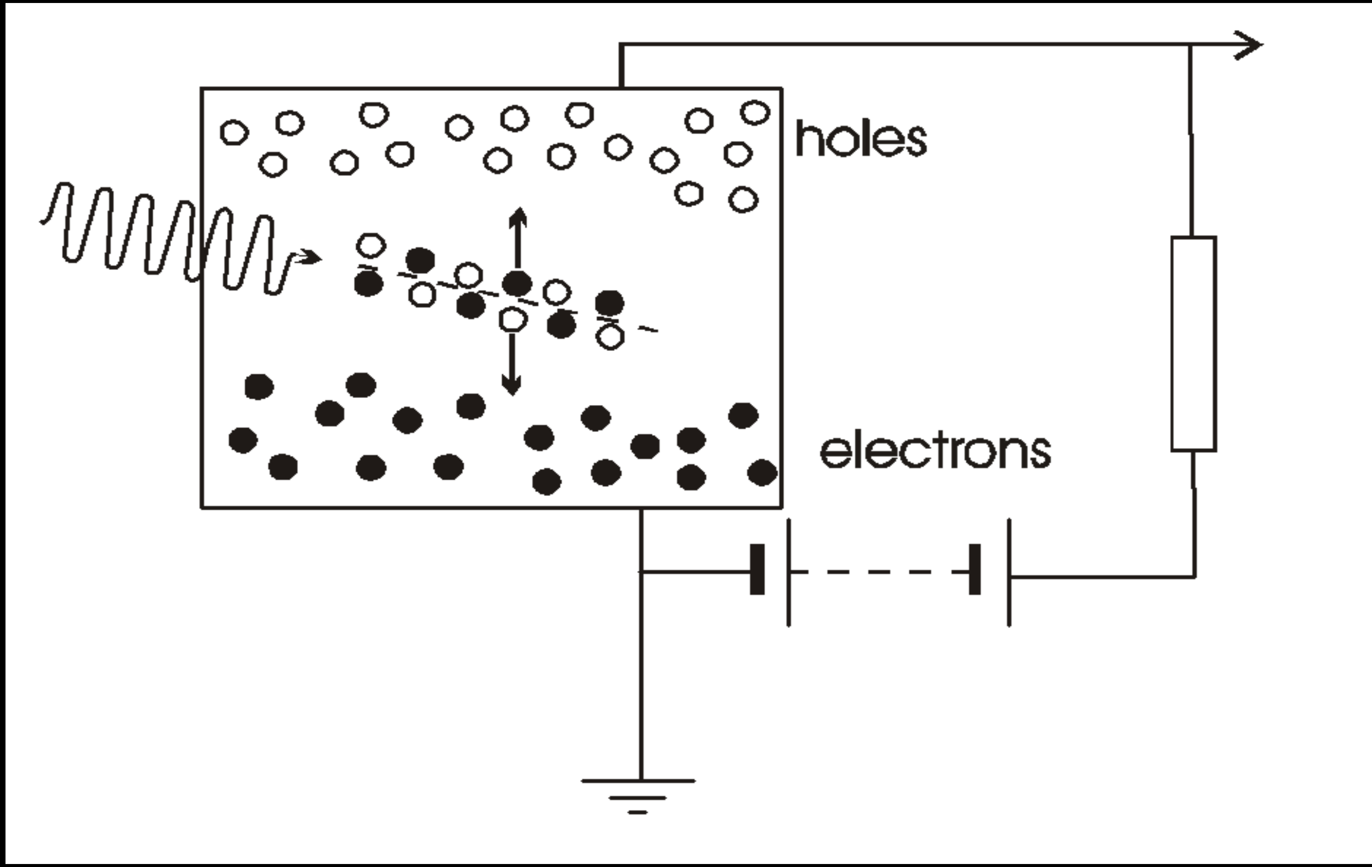


Figure 2: Principle of a semiconductor detector.

Gamma ray detectors

Advantages and Disadvantages

Each detector type has its own advantages and disadvantages.

The **NaI(Tl) detectors** are generally inferior to **Ge(Li) or HPGe detectors** in many respects, but are superior to Ge(Li) or HPGe detectors in cost, ease of use, and durability.

Germanium-based detectors generally have much higher resolution than NaI(Tl) detectors. Many small photopeaks are completely undetectable on NaI(Tl) detectors that are plainly visible on germanium detectors.

However, Ge(Li) detectors must be kept at cryogenic temperatures for the entirety of their lifetime or else they rapidly because incapable of functioning as a gamma-ray detector. Sodium iodide detectors are much more portable and can even potentially be used in the field because they do not require cryogenic temperatures so long as the photopeak that is being investigated can be resolved from the surrounding peaks.

Introduction to medical physics II

Lec 7

Dr. Shurooq Saad Mahmood

Biomedical Laser Application

Medical Lasers

Description

Medical lasers are medical devices that use precisely focused light sources to treat or remove tissues.

The term “laser” stands for Light Amplification by Stimulated Emission of Radiation.

Ordinary light, such as that from a light bulb, has many wavelengths and spreads in all directions.

Laser light, on the other hand, has a specific wavelength. It is focused in a narrow beam and creates a very high-intensity light. Because **lasers can focus very accurately on tiny areas**, they can be used for very precise surgical work or for cutting through tissue (in place of a scalpel).

Medical Lasers

Laser therapy is a medical treatment that uses a **strong beam of light to cut, burn, or destroy tissue**.

Lasers allow surgeons to work at high levels of precision by focusing on a small area, damaging less of the surrounding tissue.

The laser light beam does not pose health risks to the patient or medical team. Laser treatment has the same risks as open surgery, including pain, bleeding, and scarring. But recovery time from laser surgery is usually faster than recovery from open surgery.

Types of Laser Treatment

- Photodynamic therapy.
- Laser therapy.
- Laser surgery.

Photodynamic therapy (PDT) is a type of laser treatment that involves injecting photosensitizing chemicals into the bloodstream.

Photodynamic therapy (PDT) is **a two-stage treatment that combines light energy with a drug (photosensitizer) designed to destroy cancerous and precancerous cells after light activation**.

Photosensitizers are activated by a specific wavelength of light energy, usually from a laser. The photosensitizer is nontoxic until it is activated by light. However, after light activation, the photosensitizer becomes toxic to the targeted tissue.

Types of Laser Treatment

Photodynamic therapy (PDT)

Several photosensitizer drugs are available today to treat a variety of diseases, including acne, psoriasis, age-related macular degeneration, and several cancers, such as skin, lung, brain, bladder, pancreas, bile duct, esophagus, and head and neck.

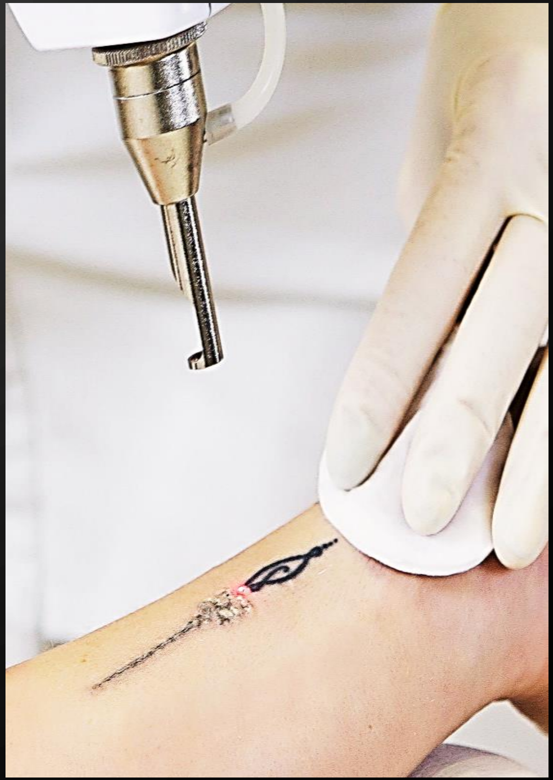
In addition to treating these conditions, PDT also helps treat bacterial, fungal and viral infections. Studies have shown that this light-based therapy can trigger the body's immune response, giving your body another means to help destroy cancerous and precancerous cells.

The uses Laser

Lasers are used in many types of surgical procedures. Some examples include:

❖ Cosmetic surgery (to remove tattoos, scars, stretch marks, sunspots, wrinkles, birthmarks, spider veins or hair).





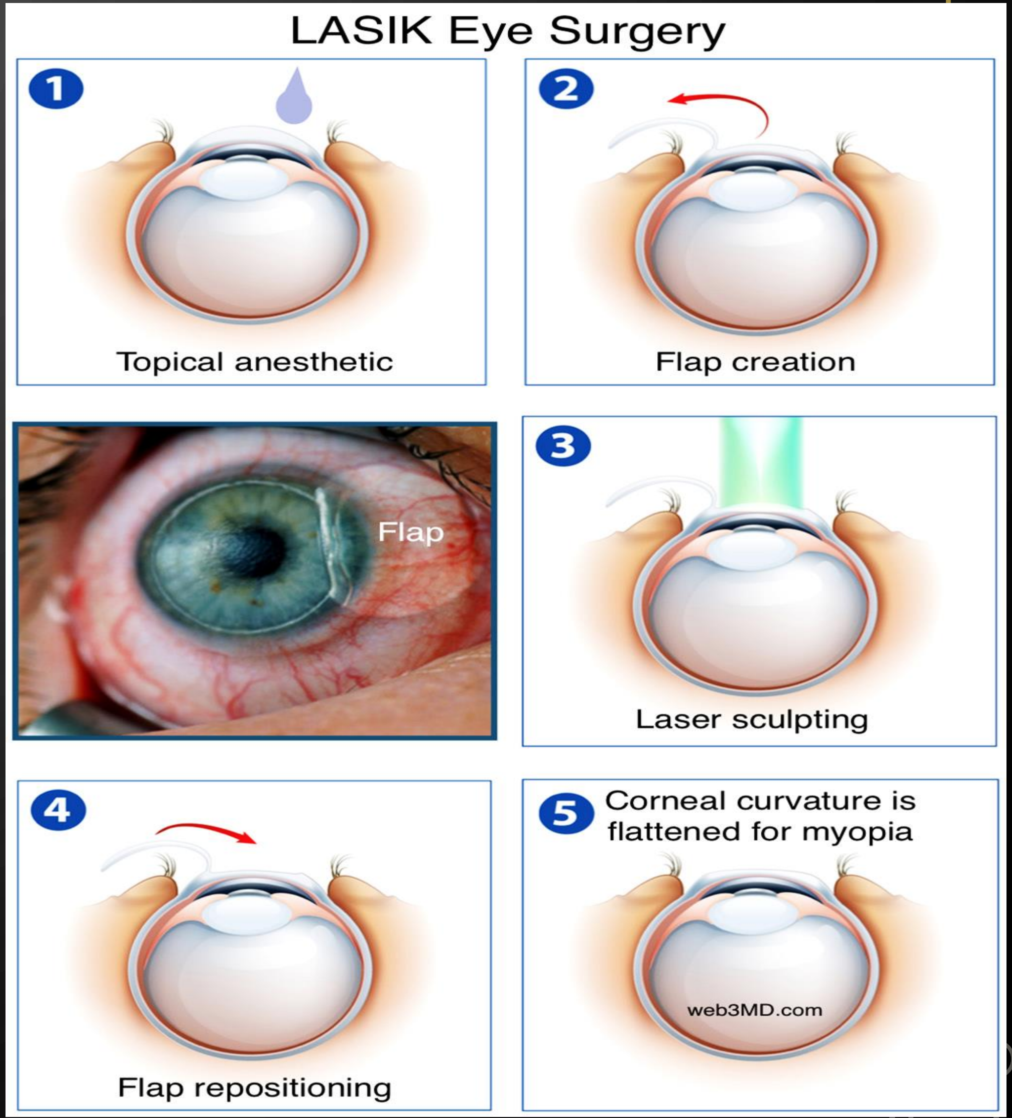
The uses Laser

Lasers are used in many types of surgical procedures. Some examples include:

- ❖ Refractive eye surgery (to reshape the cornea in order to correct or improve vision as in LASIK).

LASIK eye surgery is the best known and most commonly performed laser refractive surgery to correct vision problems. Laser-assisted in situ keratomileusis (LASIK) can be an alternative to glasses or contact lenses.

During LASIK surgery, a special type of cutting laser is used to precisely change the shape of the dome-shaped clear tissue at the front of your eye (cornea) to improve vision.



The uses Laser

Lasers are used in many types of surgical procedures. Some examples include:

- ❖ Dental procedures (such as endodontic/periodontic procedures, tooth whitening, and oral surgery)

The uses Laser

Lasers are used in many types of surgical procedures. Some examples include:

❖ Dental procedures

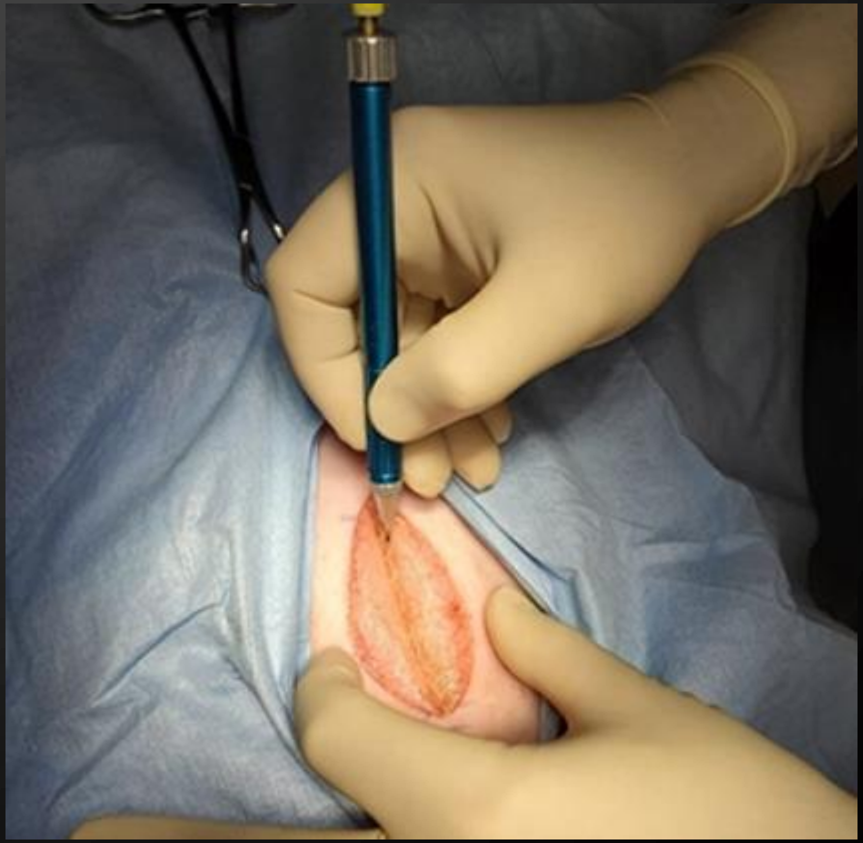
Still, some dentists are using lasers to treat:

- Tooth decay. Lasers are used to remove decay within a tooth and prepare the surrounding enamel for receipt of the filling.
- Gum disease. Lasers are used to reshape gums and remove bacteria during root canal procedures.
- Biopsy or lesion removal. Lasers can be used to remove a small piece of tissue (called a biopsy) so that it can be examined for cancer. Lasers are also used to remove lesions in the mouth and relieve the pain of canker sores.
- Teeth whitening. Lasers are used to speed up in-office teeth whitening procedures. A peroxide bleaching solution, applied to the tooth surface, is "activated" by laser energy, which speeds up of the whitening process.

The uses Laser

Lasers are used in many types of surgical procedures. Some examples include:

- General surgery (such as tumor removal, cataract removal, breast surgery, plastic surgery and most other surgical procedures)



The uses Laser

Laser therapy for cancer treatment:

- Shrink or destroy tumors, polyps, or precancerous growths, Lasers may be useful in treating the very early stages of some cancers.

Lasers are used in surgery for the cancer because they often have a special requirement that only lasers can meet—such as the ability to reach a hard to treat location, apply heat, or cut only a very small area.

For cancer, laser therapy is usually used alongside other treatments, such as surgery, chemotherapy, or radiation.

- Relieve symptoms of cancer (Palliative surgery).

Laser surgery is also used for palliative surgery in cancer patients. The purpose of palliative surgery is to help the patient feel better or function better even though it may not treat the cancer.

The uses Laser

Consider the following additional information regarding laser therapy:

- ❑ Lasers can cut a very tiny area, less than the width of the finest thread, to remove very small cancers without damaging surrounding tissue.
- ❑ Lasers are used to apply heat to tumors in order to shrink them.
- ❑ Lasers are sometimes used with drugs that are activated by laser light to kill cancer cells.
- ❑ Lasers can bend and go through tubes to access hard to reach places.
- ❑ Lasers are used in microscopes to enable physicians to view the site being treated.

The uses Laser

Laser therapy may be used to:

- Remove kidney stones.
- Remove part of the prostate.
- Repair a detached retina.
- Improve vision.
- Treat hair loss resulting from alopecia or aging.
- Treat pain, including back nerve pain.
- Treat varicose veins.

The uses Laser

Lasers can have a cauterizing, or sealing, effect and may be used to seal:

- Nerve endings to reduce pain after surgery.
- Blood vessels to help prevent blood loss.
- Lymph vessels to reduce swelling and limit the spread of tumor cells.

How is laser therapy done?

Laser therapy techniques vary based on the procedure.

If a tumor is being treated, an **endoscope** (**a thin, lighted, flexible tube**) may be used to direct the laser and view tissues inside the body.

The **endoscope** is inserted through an opening in the body, such as the mouth. Then, the surgeon aims the laser and shrinks or destroys the tumor.

In cosmetic procedures, lasers are usually applied directly to the skin.

Risks/Benefits

With proper use, lasers allow the surgeon to accomplish more complex tasks, reduce blood loss, decrease postoperative discomfort, reduce the chance of wound infection, and achieve better wound healing.

As with any type of surgery, laser surgery has potential risks. Risks of laser surgery include incomplete treatment of the problem, pain, infection, bleeding, scarring, and skin color changes.

Laser surgery uses non-ionizing radiation, so it does not have the same long-term risks as x-rays or other types of ionizing radiation.