­­­­This thesis focuses the observation of neutrons with a semiconductor detector, an active neutron detection method. For this reason, a brief introduction is given for passive detectors followed by a more extensive description of active detectors. Furthermore, a separate section is dedicated to semiconductors in addition to its mention in the current section.

**Why detector neutrons?**

Neutrons

* A neutron composites of three quarks, **up down down**.
* The electrical charge of up and down quarks are …, respectively.
* Since the net charge of the neutrons constituents is zero it is a neutron particle with no charge.
* As a result it cannot interact electromagnetically with other particles.
* Primarily, neutrons lose energy by hadronic interactions, a much stronger force, but with a significantly shorter range (10^-15m), than the electromagnetic. (so?)
* Therefore, neutrons do not directly ionize while traversing matter and are heavily penetrating particles.
* More? Reflect on the following paragraphs?

**Basic Neutron interaction**

**How to Detect Neutrons**

* Neutrons are more difficult and complex to detect than other types of radiation due to its intrinsic characteristics which causes it to interact differently with matter.
* Particle detectors rely on ionization of the sensitive volume to generate a signal
* Neutrons have zero net charge and does not interact electromagnetically with material and thus does not ionize material directly.
* Neutrons can, however, be converted into charged particles which in turn traverses and interacts with the detection medium.
* The detection of neutrons therefore rely on conversion products as neutron indicators.
* **Sequay**

**Converter Material/Reactions (THIS IS SHITTY)**

* Every type of neutron detector involves the coupling of a converter material and a conventional radiation detector.
* When exposed to a neutron source, nuclear reactions take place in the converter material and results in prompt energetic charged particles.
* Some nuclear reactions of interest in neutron detection are exoergic reactions and neutron capture reactions.
* Exoergic reactions are nuclear reactions with a positive Q-value. This means the production particles from the reaction gain a large amount of kinetic energy. Examples of exoergic reactions used for neutron conversion are B-10(n,a), Li-6(n,a) and He-3(n,p)
* He-3(n,p)
  + Because of its incredibly large cross section He-3 has for many years been widely used in neutron detection.
  + He-3 is a nobel gas and does not come in other forms, like solid and liquid.
  + After the incident of 9.11, demands in security against smuggled nuclear and radiological material skyrocketed. The quickly escalating interest in He-3 exceeded stock storages supply capability. He-3 has become costly and there is now a world wide shortage of the gas.
* B-10(n,a),
  + Probably the most popular conversion reaction is B-10(n,a). Its reaction equation can be written as: [Equation]
  + The energy available after the reaction is 4.78 MeV.
  + The interaction of neutrons with B-10 can result in one of two outcomes, one more probable than the other. In both cases the reaction products are Lithium-7 and an alpha particle.
  + In 98% of the cases the reaction results with the Lithium atom in an excited state and the remaining 2% in ground state.
  + Either way, both reaction equations yield a high Q-value.
  + Thermal neutron cross section of B-10(n,a) is 3840 barns. The reaction probability is inversely proportional to neutron speed (1/v) and decreases rapidly with increasing neutron energy.
  + Natural abundance of Boron is 19.9% ([\*](https://physics.nist.gov/PhysRefData/Handbook/Tables/borontable1.htm))
* Li-6(n,a)T
  + Another widely used reaction is Li-6(n,a)T.
  + Reqaction equations
  + The reactions cross-section for thermal neutrons is 940 barns. Similar to Boron, the reaction probability decreases with neutron energy (1/v) up to 100keV, the resonance region. Here the reaction cross section peaks above boron and even that of He-3
* Gadolinium

Detection eff. Og 50% ish?

So far studies of Gd couples with

The use of Gd as a neutron converter is wuite appealing and there have been conducted many studies

What type of detectors apply Gd?

Comment on todays status of GD

What forms does Gd come in?

[reflecting on what you just read about reactions and conversion materials]

* Most reactions, and therefore also neutron detectors, favor slow (thermal) neutrons, except for those based on elastic scattering where cross sections are large for highly energetic, fast neutrons.
* Favored conversion materials are those with a large reaction cross section (high neutron conversion probability) and high q-value (for better gamma discrimination).
* Different types of reactions available in different forms, allows us to transform most particle detectors into neutron sensitive devices.

**Neutron detectors (state of the art?)**

Regular particle detector to neutron detector, first the detection principles of most commonly used detectors in neutron detection. how to modify these further to become neutron sensitive. Including examples

There are many different methods for detecting neutrons. They can be grouped into two categories: active and passive. Passive methods yield information after irradiation is complete. In contrast, active methods monitor neutron presence in real time.

Examples of **passive detectors** are: thermoluminescent, etched-track, and nuclear-emulsion detectors. Passive detectors do not need a power supply, do not experience any electromagnetic interference and respond well to high-energy radiations. For these reasons, passive detectors are commonly used in areas involving high-energy dosimetry. Nuclear track emulsion is the oldest method of neutron personal dosimetry. ([\*](https://watermark.silverchair.com/nch129.pdf?token=AQECAHi208BE49Ooan9kkhW_Ercy7Dm3ZL_9Cf3qfKAc485ysgAAApIwggKOBgkqhkiG9w0BBwagggJ_MIICewIBADCCAnQGCSqGSIb3DQEHATAeBglghkgBZQMEAS4wEQQMmjOgYv5S7D7kdhETAgEQgIICRbTB5j39f9ufWccHJM0DDGB1k7UuRgKZQRlBdKhbpBgB8Xs9hz6Y0uw4iV7-IMFBvsYbM_yM5OcllScoEIHVDsmN8J51lBXAGE3hjX_E8OAHq-7S79rnPndj3jD2uuw56FLqEGbYby2tA0x1Te1bjRftELelKcUKYrRQobCoLaJLwGWrcOfZgyMQ-hWO_wKAlxvL7cKuV7MygjcPjbWVUVwHNRjWPkx9xMGrVc_RPKR48__vi1laCF5_4HHxXQgEraqOSw_3eaFGOWqTtUFeJKBagkqHCakGd9xYTcU5EZFjOW7fSEnT9Zs7LFD3-IZy5mhSU3wT2arZ4RR4VTwoyjFfa7rlXLBjAZ-EfNGah1h6WOwQYTm5POUge6SDun5aUSXiW07G3UOY2DTwcB9Z_4720Q6pWVuStJUQy-GjIhXUqNNZemXkOPGwaAy2O6fC4oyBtU4xR1Syviodw-LywtVqq2i2-UQ4Ph4zfz0c5ZskCBXmDCLNDJt5JioY7aoRoNQKWkYqYsh3HgM-C3-o7HJFDIUL4xKysyY78pfW9b3wQAjob8_uQrfO8IjC5G3225ULuHIrjph8xWCd8-7WSNxXqeQ2j3Sc6MMvIioISJBjNXA1n_MxHx4ZsgL1Po6Cy-ec5KHFh2nPyxRyQKyNECKf-vDxgf0W9WuRI4WrHuIvVtuLqq4F8J0kSC5ZPvV3qaso07tofTcMF4GoA8BOSmVT2xmHghlalLnAqiVAyn45ce6sCxQB6SuA5s6UhN6THOJa6Jfx))

Active neutron detection methods have a wide range of applications like tracking movement of water in plants, providing compositional information on metallic cultural artifacts, and determining the structure of crystalline solids (Kilde: Advances in neutron radiography and tomography). + other examples than just imaging

A relatively new development is active personal dosimeters (APD). Even though they compete with passive methods, there is still progress to be made with respect to energy-dependency. The most important **active methods** are those using gaseous detectors, scintillators and semiconductor detectors.

**The basic particle detector**

*The sensitive volume*

One of the major components of a particle detector is the sensitive volume. In gas detectors this volume is filled with, intuitively enough, gas. In semiconductors a solid material fills the volume. Scintillators may incorporate material of either gas, liquid or solids, depending on detector application and requirements.

Since semiconductors incorporate solids they are often referred to as “solid-state” detectors. This is, however, somewhat ambiguous as scintillators may also utilize solids and thus can be solid-state detectors as well. It would not be wrong to call the latter by the former, though it is not commonly done. From here on out, the term solid-state refers to semiconductors alone.

Incoming radiation interacts with the sensitive volume and one way or another create electrical charges responsible for a detector signal. The radiation may produce charge carries directly, like in gas detectors (ion pairs) and semiconductors (electron-hole pairs), or cause a process which subsequently produce charge carriers, like in scintillators (photoelectrons).

GAS DETECTORS

The basic components of a gas detector is the gas-filled chamber (i.e. sensitive volume) and electrodes (cathode and anode, i.e. the charge collectors). In general the outer chamber-wall (cathode) is most often spherical or cylindrical and encompasses the anode, usually rod-shaped. A voltage is applied to the collector plates and gives rise to an electric field between the two.

When an energetic particle enters the gas-filled chamber the gas molecules are ionized. With enough energy the incoming particles can tear an electron from its atom and produce an ion pair. The electric field between the collector plates attract the newly created charges, the positive ion to the cathode (-) and electron to the anode (+).

A charged particle in an electric field experiences a force and the magnitude of its acceleration depends on the particles mass. The electron and ion are surrounded by the same electric field, but the electrons significantly smaller mass (??) causes it to accelerate at a considerably larger rate. The electron is thus the first of the two to be collected. The speed at which charge carriers are collected depends on the chamber pressure and the applied field strength.

Gas detectors are classified based on the voltage range, i.e. the field strength between collector plates, at which it operates. The three basic types are: Ionization chambers, proportional, Geiger-muller counter. Geiger-muller counter has difficulties detecting secondary particles of neutrons, however, it may be used to detect neutron induced gamma-rays. There will be no further discussion of Geiger-muller counters. (source?) Something more on field strength?

Ionization chambers

Out of the three gas detectors, the ionization chamber operates at the lowest voltage. For neutron detectors the field strength typically lies in the range 200-4000 V. (?)

Proportional counters

* Since neutrons cannot ionize matter, the detector must be coupled with a material convert the non-ionizing particle into one or more detectable particles. The signal generating particles can be created by either the chamber gas itself (e.g. boron enriched BF\_3 counting gas) or by a radiator inside the chamber (e.g. boron chamber lining).

Material properties of the sensitive volume plays a major role in how the detectors responds to radiation.

Neutron detectors operate at higher V than normal particle detectors??