Neutron detectors

Neutron sources

Neutrons are particles with zero net charge. They appear in laboratories from …, airplane highs due to …, nuclear reactors, nuclear weapons and more. The last years there has been a growth of fields dealing with neutrons: storage of nuclear waste, search for illicit trafficking and hidden nuclear materials, and increased awareness in aviator hights(?).

The He-3 gas counter widely used, but there is a shortage of He-3. Motivation for developing alternative neutron detection methods. Gd- up and coming? Increased focus on Gd?

Neutrions are ahdronic particles contituing three quarks whos charge sum equals zero. In other words the neutron has no charge and does not interact through electromagnetic forces. IT does, owever interact with the hadronic force, which is strong, but has a very short range (10^-15m). Because it doesn’t interact with matter through electromagnetic force it does not ionize matter. It does however ionize indirectly. Neutrons may interact through hadorinc processes, which produce otherparticles (of charge) such as electrons and protons, and these are directly ionizing particles. Neutrons must therefor first be converted into otherparticles to be detected. This is done using a convertermaterial. The converte material may be gad, liwuid or solid.

The most common neutron detector is the gas proportional counter (?). A widely used convertermaterial is He-3 which brings many good qualities such as high count rate, fast countrate(?), A gas chamber is only a counter and does not give information about energy deposition.

Information about neutron energy is difficult to track and is still being developed?? (find any ref?)

The most common use of neutron detectors are counters. Active counters are gas, solid-state and scintillators.

Gas detectors (1/4) (particles of interest?, pros and cons? Set up? Most popular design? Cost? Efficiency?)

Scintillation (1/4)

Solid state (2/4)

There are many diffrent types of neutron detectors and the requirements for each is depedent on their field of use. For instance, in dosimetry a high persistion energy resolution and spatial resolution is required to give an accurate treatmentplan. On the other hand, energy deposition is not of interest in fields where only the activity of neutron flux is of intterest, such as in nuclear reactor monitoring to reulate neutrons bombarding fissile material.

The use of detect

Gas

Solid state

Scintillators

Requirements

Speed

Efficiency

Energy deposition

Spatial resolution

Convertermaterial

He-3

Gd

B-10

Li-6

??

Active

Passive

Examples

Nuclear Weapsons

Illicit trafficking and hidden nuclear materials

Radiation safety

Nuclear reactors

Nuclear storage

Neutron sources

Neutrons

Zero net charge

Indirecyly ionizing

Strongly penetrating radiation

Nuclear reaction

Reaction products

Q-value

Thermal energy

Neutron energy

Reaction cross section

What are neutrons?

**FOREWORD(?)**

This thesis focuses on semiconductor neutron detectors, 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/chapter is dedicated to semiconductors in addition to its mention in this section.

**WHY DETECT NEUTRONS?**

* There are many fields(?) in physics dealing with neutrons in which detecting neutrons is essential(?).(3 examples why. There are plenty more, but no need to list them all)
* The following exemplify the vast scope of neutron detection application.
* Nuclear Reactors (read more about this)
  + Are dependent on neutron detection to regulate and monitor oporations???
  + Neutron induced reactions, U-235.
  + Produce two/three neutrons
  + Cascade of reactions, exponential growth of neutrons(?)
  + If incident neutron flux too high, cascade escalates out of hand and it can have lethal consequences(?) .
  + E.g. Hiroshima?
  + Monitoring neutron flux allows us to keep reactor in stable conditions and calibrate neutron flux as needed to *prevent* *accidents*/ *maintain controll*.
  + Reference?
* Nuclear weapons (read more)
  + Contain traces of unstable radionuclides?
  + Many nuclear materials produces alpha, beta, gamma and neutrons. The first three are easy to shield, neutrons less so.
  + Neutron detection methods are therefore beneficial in the search of illicit trafficking of nuclear and other radiative materials.
  + neutron detection is an essential part of a comprehensive nuclear security program to prevent nuclear proliferation and possible construction of nuclear devices.
  + E.g. Plutonium (?)
  + Reference?
* Due to the development of new fields dealing with neutrons, for instance neutron spallation sources, neutron detection has become increasingly important
  + ESS??
  + What do they do
  + Why do they want/ is it important for them to track neutrons?
* Neutron imaging (ref. M Strobl 2019)
* Moreover, the detection of neutrons has allowed for the development of neutron imaging, a technique complementary to x-rays and other types radiation. Unlike x-rays, neutron attenuation does not depend on the atomic number of the penetrated material. Imaging with neutrons can therefor reveal structural information not attainable by x-rays. For instance, blood vs bones (synonyms for neutron imaging)
* A neutron beam is a non-invasive analyzing tool and has been of great benefit to feilds like biology, geography archeology, to name a few. (E.g. look inside articfacts without destroying them)
* These are just a few example, the scope of neutron detection applications is wide and it would be difficult to summarize them all. (ref. to reviews of neutron detections applications?)

**NEUTRONS**

* Have Zero net charge
* Are penetrating particles (penetrating radiation)
* Interact with hadronic force
* Have a short interaction range (10^-15m)
* Do not interact electromagnetically
* Are Indirectly ionizing (non-ionizing)
* Allow for non-destructing and non-invasive(?) imaging instruments

**BASIC NEUTRON INTERACTION** (new chapter?)

* Summary of neutron interaction with matter

**HOW TO DETECT NEUTRONS?**

* Most (all?) particle detectors are based on ionization to produce a signal. An incoming particle strikes the detectors sensitive volume and by electromagnetic forces creates signal generating charge carriers (electrons).
* Neutrons have zero net charge and does not interact electromagnetically with material, they cannot not ionize material directly.
* Neutrons can, however, be converted to charged particles which in turn (?) activate a signal in the detector.
* Neutron detection relies on reaction products of neutron conversion as neutron indicators.

**CONVERTER MATERIALS**

* Must attribute high neutron abos. Prob?
* Gadolinium (another chapter): short summary

**TYPES OF NEUTRON DETECTORS?**

* 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 in 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))
* The most important **active methods** are those using gaseous detectors, scintillators and semiconductor detectors.
* 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).
* 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.

Form

* Basic principle
* Status today?
* Application
* Pros/cons

**GAS-FILLED DETECTORS**

* Basic principle?
* Most important counting gasses: He-3, B and Li (ref?)
* He-3 and B-10 high Q-value such that charged particles exceed detection thresholds
* He-3 is most commonly used in proportional counters.
  + Pros: high Q-value such that charged particles exceed detection thresholds, good detection efficiency (up to 90%)
  + Cons.: Shortage of He-3 (and expensive?) (find ref)
* Cons: bulky and expensive to use

**SCINTILLATORS**

* Basic principle? (doped scintillator material, photomultiplier tube to enhance the signal
* Of various types are seen as and alternative to gaseous detectors.
* Are sensitive to amount of energy deposited
* Pros: easy to operate, cheap, robust, fast (can be used for time of flight measurements)
* Cons: prone to radiation damage (?), problems w/ magnetic fields(?), poor neutron-gamma separation, aging effects
* Application: used in neutron imaging, spacious, CCD cannot lie in neutron path, therefor semiconductors are better.

**SEMICONDUCTORS (+ chapter)**

* Basic principle:
  + Ionization of active volume.
  + Generation of charge carriers (information carriers) analogous to electron ion pair in gas-filled detectors.
  + Produce more information carries and thus have a greater energy resolution.
* Practically available in 1960 (Ref. Glenn Knoll(nødvendig å ha med?))
* The primary semiconductor material is silicon. Such detectors operate sufficiently in room temperature, while detectors based on germanium need cooling to minimize thermally generated current leakage (explain what this is or mention in section with semiconductor?).
* Its compact size is preferable in medical imaging, above the bulky scintillator, however, the limitation thereof is negative in applications requiring large detector surfaces. / Are compact and small in size, one of the reasons making them more desirable than large, bulky gas-filled detectors.
* Pros: compact, lightweight, less expensive to fabricate, operates at lower voltages
* Cons: ?