Introduction

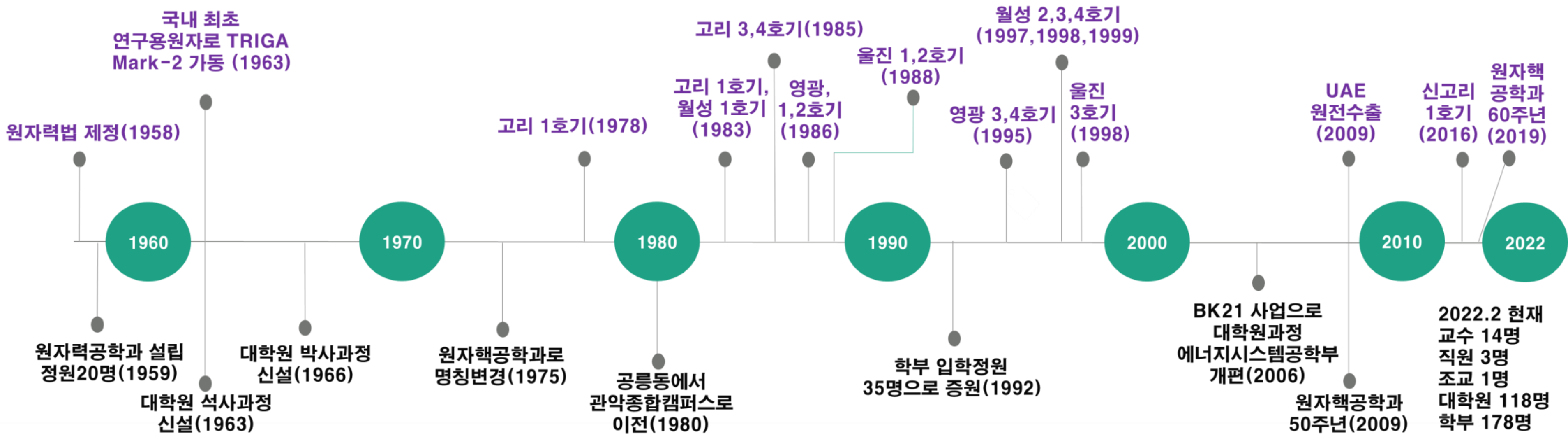
Fall, 2022

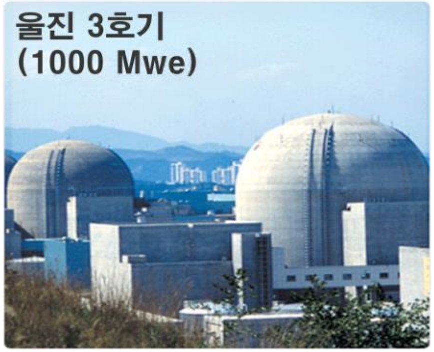
Kyoung-Jae Chung

Department of Nuclear Engineering

Seoul National University

Department of Nuclear Engineering





Department of Nuclear Engineering

- **원자핵 공학이란?**
  - 원자핵을 기원으로 하는 에너지와 입자를 활용하여 인간에게 편익을 주는 기술의 개발과 이용을 다루는 학문

- **원자력 시스템 분야 → 핵공학개론 1**
  - 핵분열에너지를 이용한 발전과 고온열 생산
  - 안전한 원자력발전소의 설계, 건설, 운영에 필요한 제반 기술

- **핵융합•플라즈마 분야 → 핵공학개론 2**
  - 핵융합에너지를 이용한 발전과 플라즈마 활용
  - 디스플레이/반도체 제조 기술, 친환경, 의료, 국방 기술 등

- **방사선•아원자입자 분야 → 핵공학개론 2**
  - 방사선을 이용한 질병의 진단과 치료(X-ray, PET, BNCT)
  - 비파괴 검사 및 탐색, 개질(신소재 개발), 정밀 계측, 방사선 생명공학 등
  - 입자(전자, 양성자) 가속기, 중성자 발생장치 등

SNU-NE covers

원자력 시스템 공학

핵분열에서 발생하는 높은 에너지를 이용하는 발전소 시스템을 연구하는 분야.

원자로 물리

- 전산 원자로 물리
- 다물리 원자로 시뮬레이션
- 고성능 컴퓨팅

Reactor Physics Lab.
주한규 교수

- 원자로 물리
- 몬테카를로 시뮬레이션
- 불확도/수치 해석

Monte-Carlo Lab.
심형진 교수

원자력 재료

- 원자력 재료
- 분자동역학
- 원자론적 전산모사

Nuclear Materials Modeling Lab.
오다 타쿠치 교수

- 핵연료 재료 실험, 해석,설계,
- 사용후핵연료 거동 연구
- SMR/초소형 원자로 재료

Nuclear Fuels Materials Safety Lab.
이유호 교수

원자력 열유체 및 시스템

- 고성능 전산모사
- 원자력 안전/중대사고
- 혁신 원자로 시스템

Nuclear Energy System Lab.
김응수 교수

- 고성능 열수력 현상 전산모사
- 이상유동
- SMR/초소형원자로

Nuclear Thermal-hydraulic Engineering Lab.
조형규 교수

핵연료주기

- 핵폐기물
- 핵연료 재처리
- 핵비확산

Nuclear Fuel Cycle Nonprolieration Lab.
최성열 교수

SNU-NE covers

핵융합/플라즈마 이론

"Theoretical approach for fusion plasma physics"

- Tokamak turbulence theory
- Transport barrier physics
- Modern gyrokinetic formalism
- Gyrokinetic simulation
- Gyrofluid simulation

함 택 수
Hahm, Taik Soo

핵융합/플라즈마 실험

"Experimental approach for fusion plasma physics and fusion-related technology"

황 용 석
Hwang, Yong Seok

- Tokamak experiment (VEST)
- Heating and current drive
- Fusion plasma diagnostics
- Ion beam source
- Fusion neutron diagnostics

핵융합/플라즈마 전산모사

"Computational approach for fusion plasma physics"

- Tokamak operation scenario
- Integrated modeling and control of tokamak plasmas
- Plasma transport and stability analysis

나 용 수
Na, Yong Su

플라즈마 산업 응용

"Experimental approach for physics and applications of low temperature plasmas"

김 곤 호
Kim, Gon Ho

- Sheath physics
- Plasma diagnostics
- Dry etching/PECVD/PEALD
- Plasma surface interaction
- Bio/agriculture applications

방사선 방호/ 방사선 생체의료 공학

김은희 교수

- Radiation Biology
- Radiation Protection
- Radiation/Plasma Therapy
- Radiation Source Characterization
- Radiation Risk

방사선 기기공학/펄스파워 공학

정경재 교수

- Plasma Ion Source
- Particle Accelerator
- High Energy Density Physics
- Pulsed Power
- Plasma Application

방사선 계측 공학

김기현 교수

- Radiation Measurement & Application
- Radiation Detector Development
- Radiation Imaging Technique
- Radiation Detection Methods

Nuclear system engineering

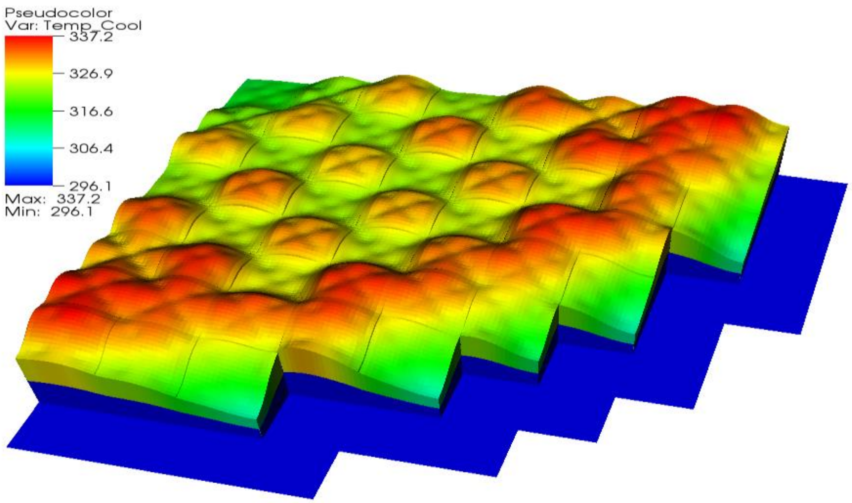
- Reactor physics

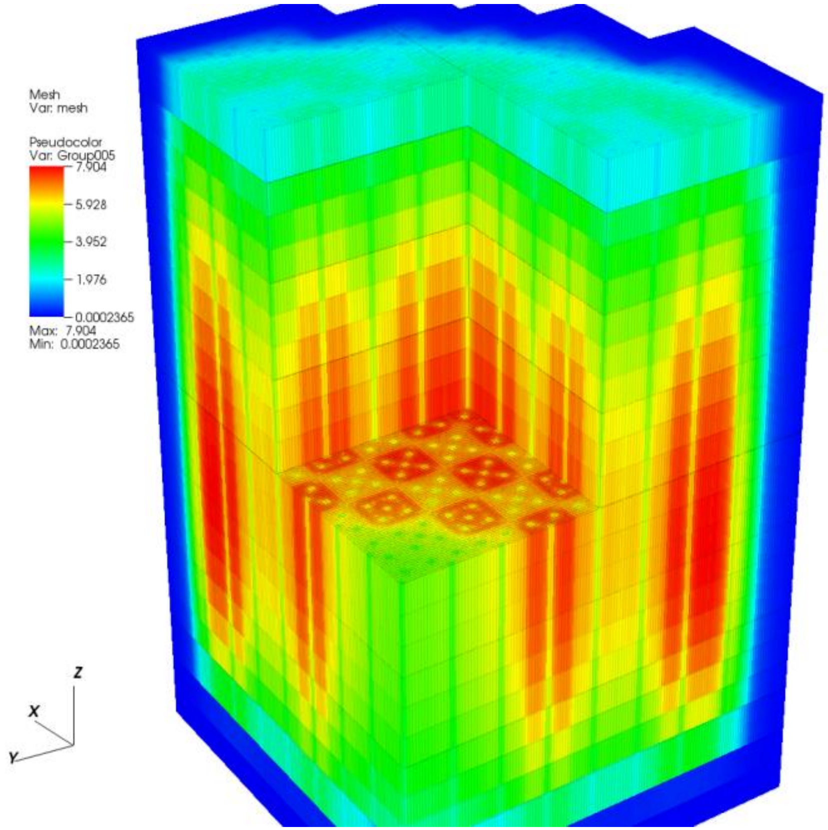
Boltzmann neutron transport equation

$$\hat{\Omega}\cdot\nabla\varphi(\vec{r},E,\hat{\Omega})+\Sigma_t(\vec{r},E)\varphi(\vec{r},E,\hat{\Omega})=\int_{\Omega'}\int_{E'}\Sigma_s(\hat{\Omega}'\rightarrow\hat{\Omega},E'\rightarrow E)\varphi(\vec{r},E',\hat{\Omega}')dE'd\hat{\Omega}'+\frac{1}{4\pi}\chi(E)\psi(\vec{r})+s'''(\vec{r},E)$$

Navier-Stokes equation

$$\frac{\partial\rho\mathbf{v}}{\partial t}+\nabla\cdot(\rho\mathbf{v}\mathbf{v})=-\nabla p+\nabla\cdot\mathbf{T}+\rho\mathbf{g}$$





Nuclear system engineering

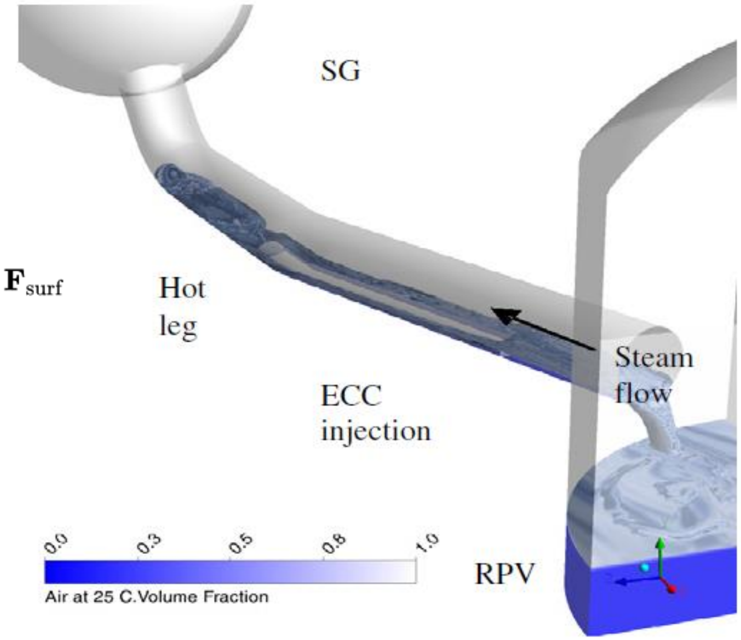
- Thermo-hydrodynamics

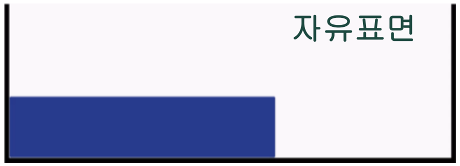
Hydrodynamic equations

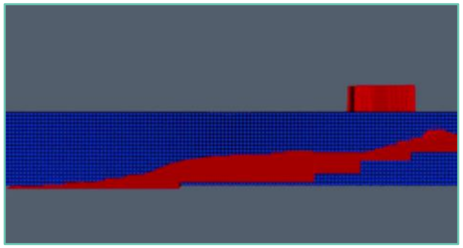
$$\frac{\partial}{\partial t}\iiint_V \rho \, dV = -\oiint_S \rho \mathbf{u}\cdot d\mathbf{S}$$

$$\frac{\partial}{\partial t}\iiint_V \rho \mathbf{u} \, dV = -\oiint_S (\rho \mathbf{u}\cdot d\mathbf{S})\mathbf{u} - \oiint_S p \, d\mathbf{S} + \iiint_V \rho \mathbf{f}_{\text{body}} \, dV + \mathbf{F}_{\text{surf}}$$

$$\rho \frac{Dh}{Dt} = \frac{Dp}{Dt} + \nabla\cdot(k\nabla T) + \Phi$$







쓰나미 전파

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Fusion & plasma engineering

- Fusion plasma physics: Magneto-hydrodynamics or kinetics

Boltzmann transport equation

$$\frac{\partial f}{\partial t} + \frac{\mathbf{p}}{m} \cdot \nabla f + \mathbf{F} \cdot \frac{\partial f}{\partial \mathbf{p}} = \left(\frac{\partial f}{\partial t}\right)_{\mathrm{coll}}$$

Hydrodynamic equations

$$\frac{\partial}{\partial t} \iiint_V \rho \, dV = - \oiint_S \rho \mathbf{u} \cdot d\mathbf{S}$$

$$\frac{\partial}{\partial t} \iiint_V \rho \mathbf{u} \, dV = - \oiint_S (\rho \mathbf{u} \cdot d\mathbf{S}) \mathbf{u} - \oiint_S p \, d\mathbf{S} + \iiint_V \rho \mathbf{f}_{\mathrm{body}} \, dV + \mathbf{F}_{\mathrm{surf}}$$

$$\rho \frac{Dh}{Dt} = \frac{Dp}{Dt} + \nabla \cdot (k \nabla T) + \Phi$$

Maxwell equation

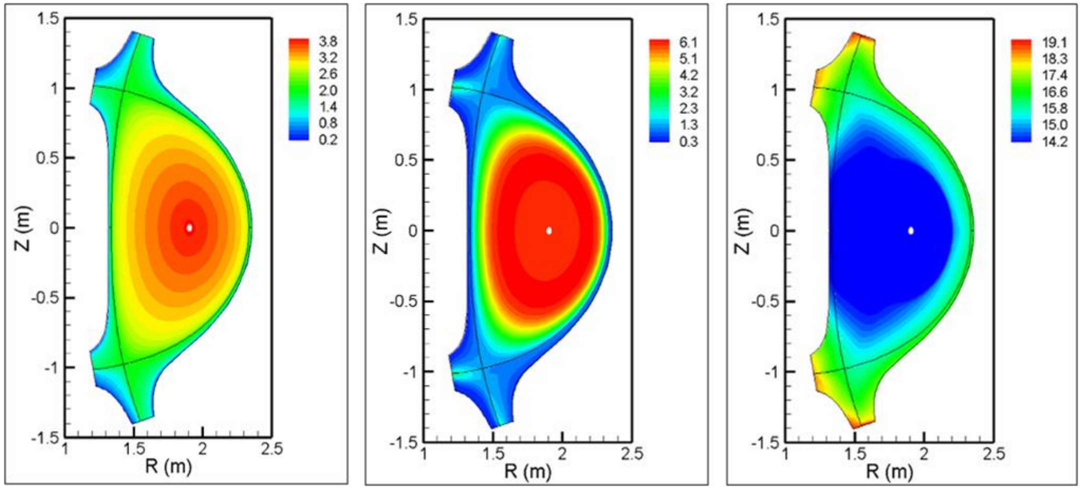
$$\nabla \cdot \mathbf{D} = \rho$$

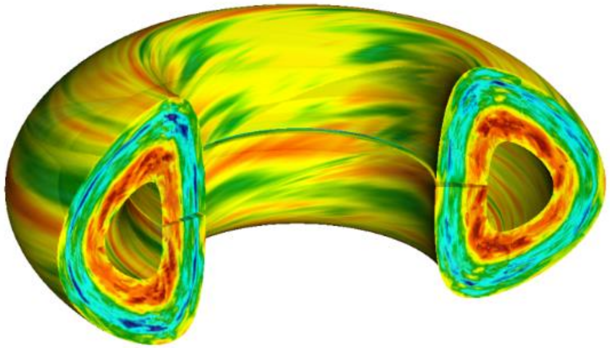
$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

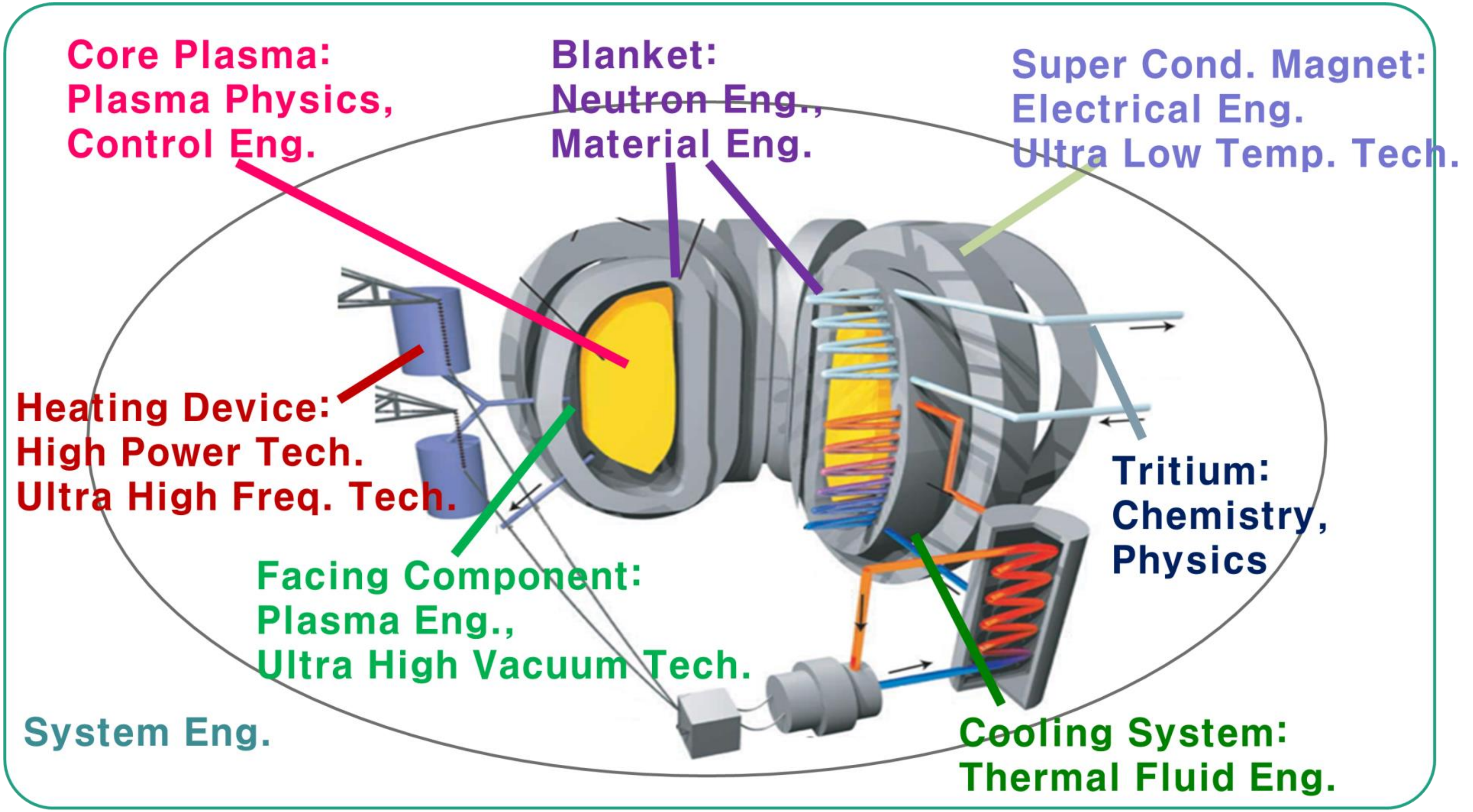
$$\mathbf{F} = q \mathbf{E} + q \mathbf{v} \times \mathbf{B}$$





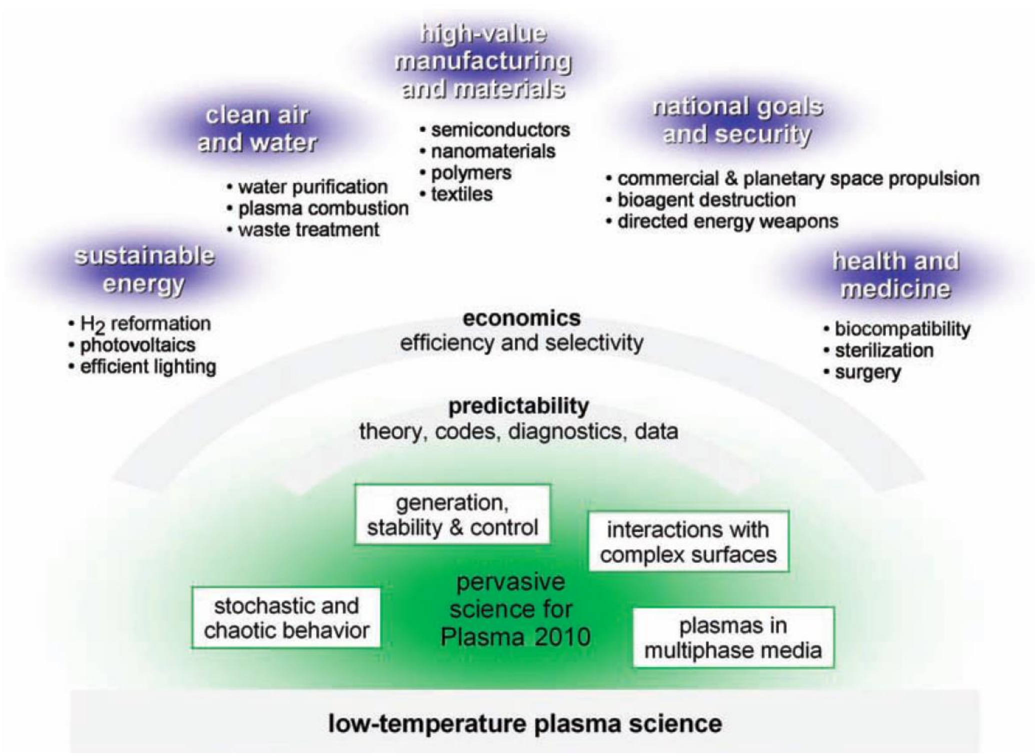
Fusion & plasma engineering

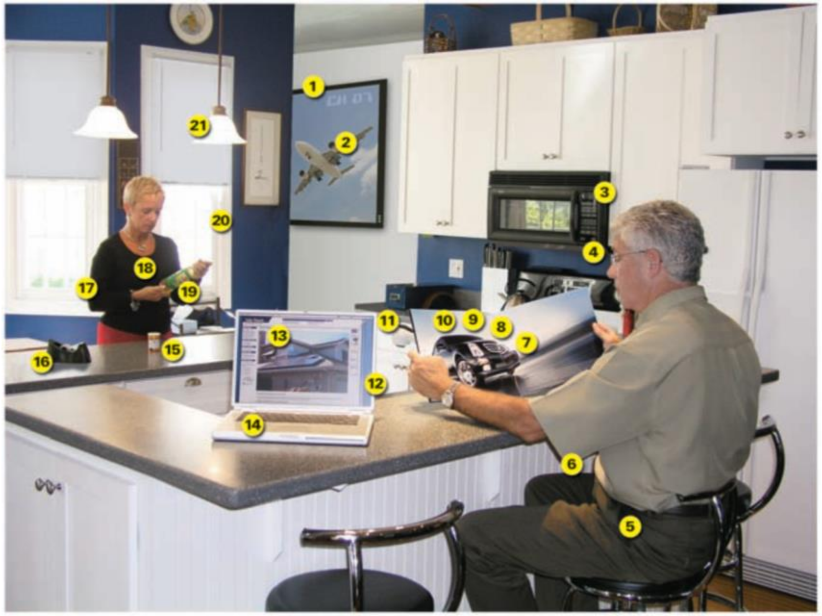
- Fusion reactor engineering



Fusion & plasma engineering

- Plasma applications



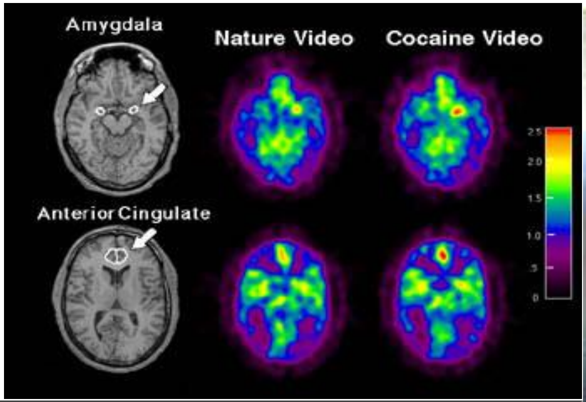


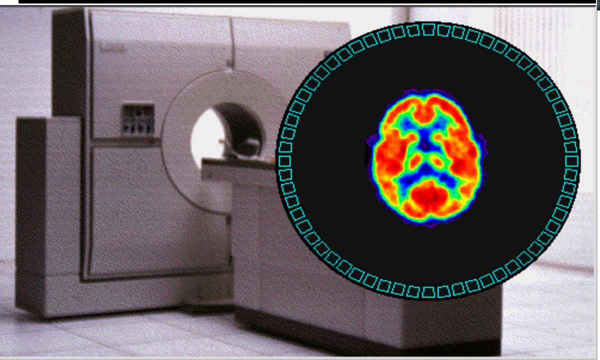
01—Plasma TV
02—Plasma-coated jet turbine blades
03—Plasma-manufactured LEDs in panel
04—Diamondlike plasma CVD eyeglass coating
05—Plasma ion-implanted artificial hip
06—Plasma laser-cut cloth
07—Plasma HID headlamps
08—Plasma-produced H_2 in fuel cell
09—Plasma-aided combustion
10—Plasma muffler
11—Plasma ozone water purification
12—Plasma-deposited LCD screen
13—Plasma-deposited silicon for solar cells
14—Plasma-processed microelectronics
15—Plasma-sterilization in pharmaceutical production
16—Plasma-treated polymers
17—Plasma-treated textiles
18—Plasma-treated heart stent
19—Plasma-deposited diffusion barriers for containers
20—Plasma-sputtered window glazing
21—Compact fluorescent plasma lamp

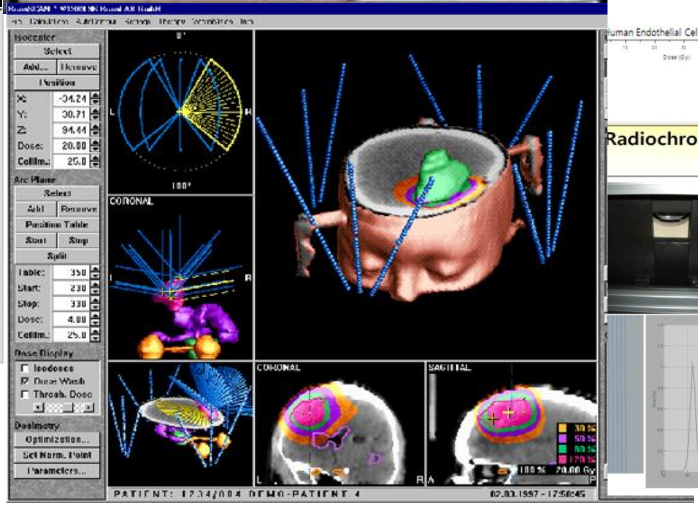
Plasma Science: Advancing Knowledge in the National Interest (2007)

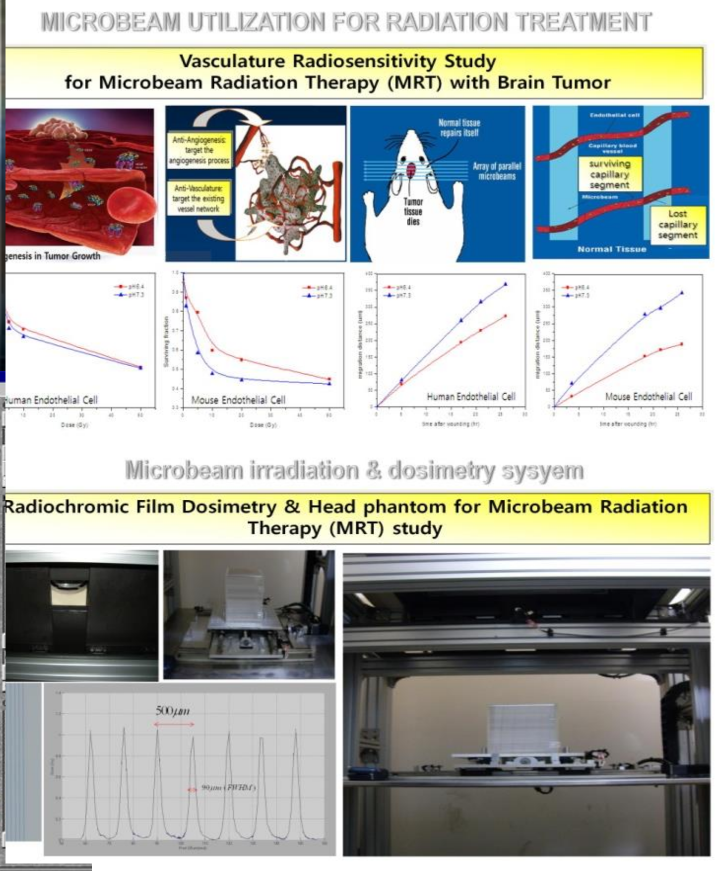
Radiation engineering

- Radiation biology and medical application



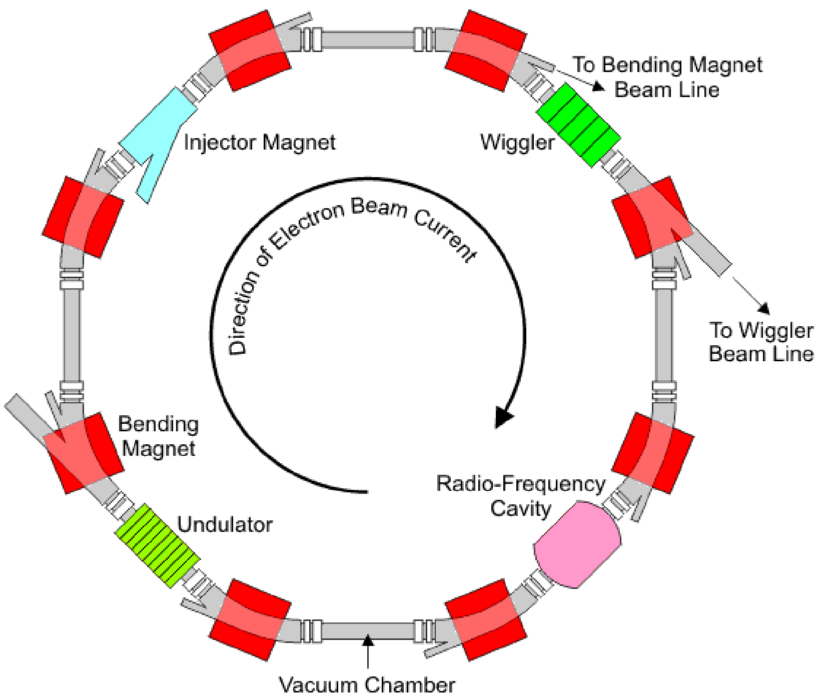


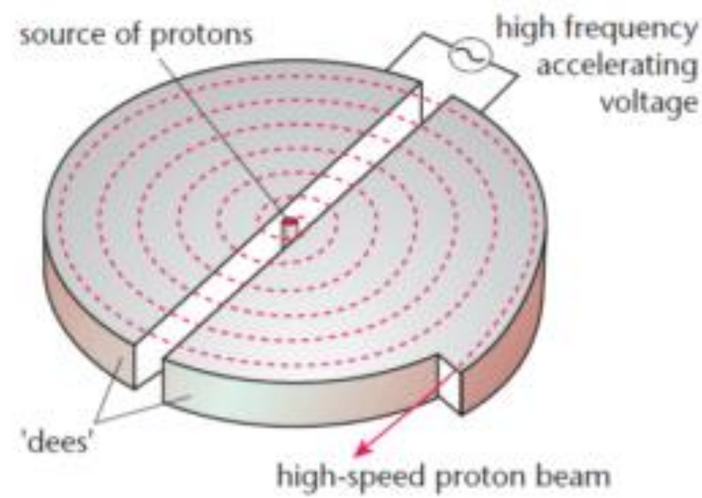


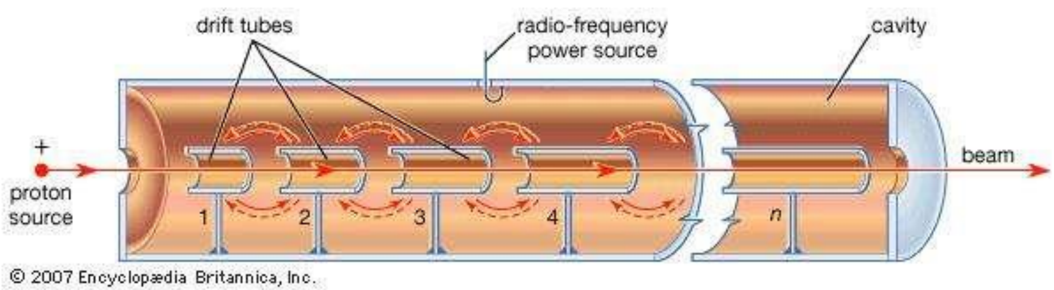


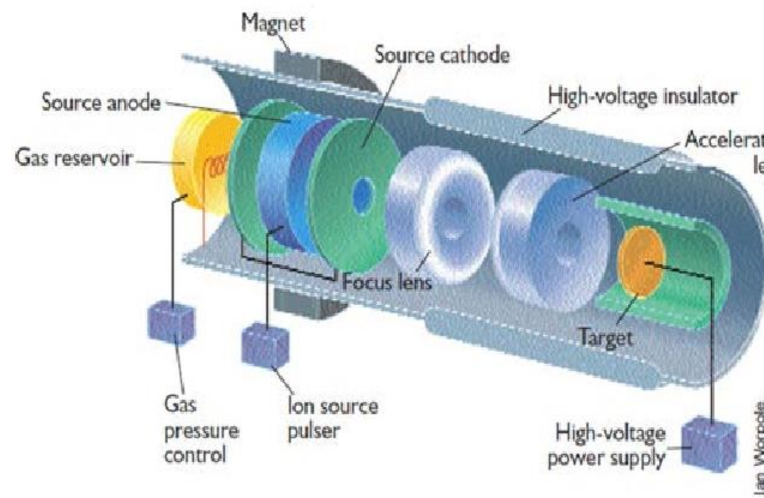
Radiation engineering

- Radiation source and particle accelerator









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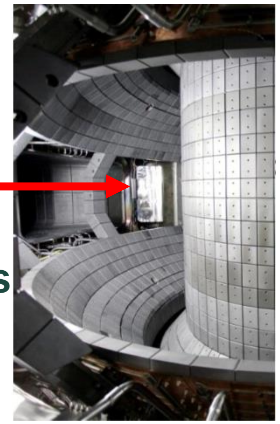
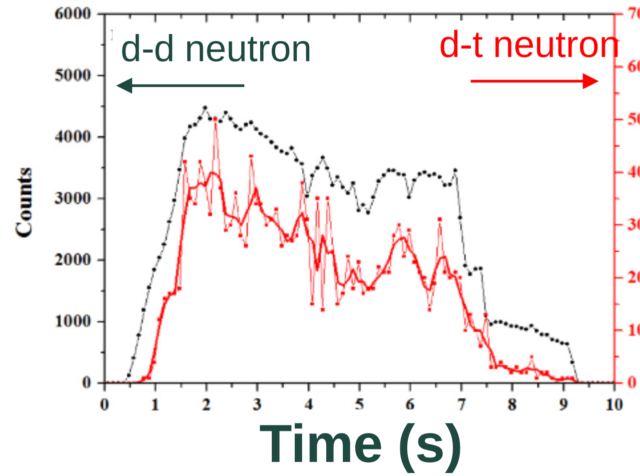
Radiation engineering

- Radiation detection and measurement

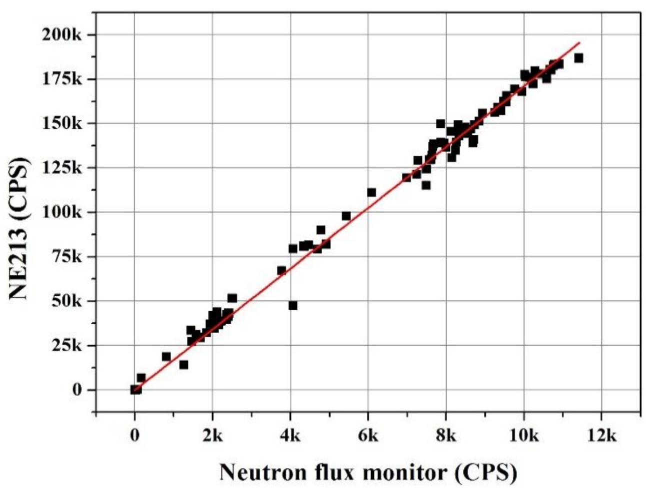
NE213 scintillation detector

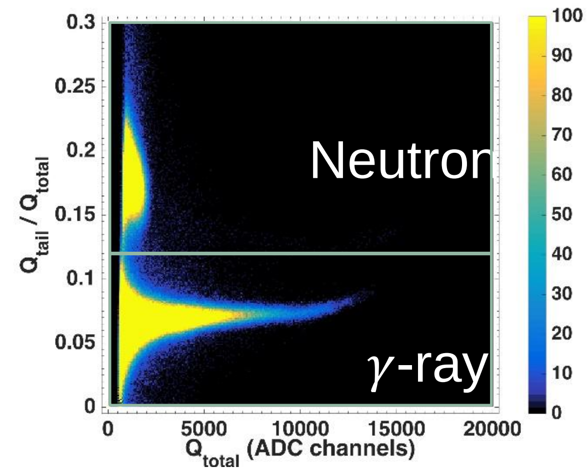
8.2 m from magnetic axis





- **Radiation shield**
- **Linearity with conventional NFM**
- **Neutron and gamma ray discrimination**





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Syllabus of Nuclear Engineering 2

- **Radiation engineering**
  - Radiation and radioactivity
  - Radiation interaction with matter
  - Radiation source technology
  - Detection and measurement of radiation
  - Radiation dose and hazard assessment
- **Plasma engineering**
  - Basic concepts of plasma
  - Plasma and sheath
  - Plasma source technology
  - Plasma applications and related issues
- **Fusion engineering**
  - Fusion energy
  - Various fusion concepts
  - Tokamak
  - Issues in fusion nuclear technology

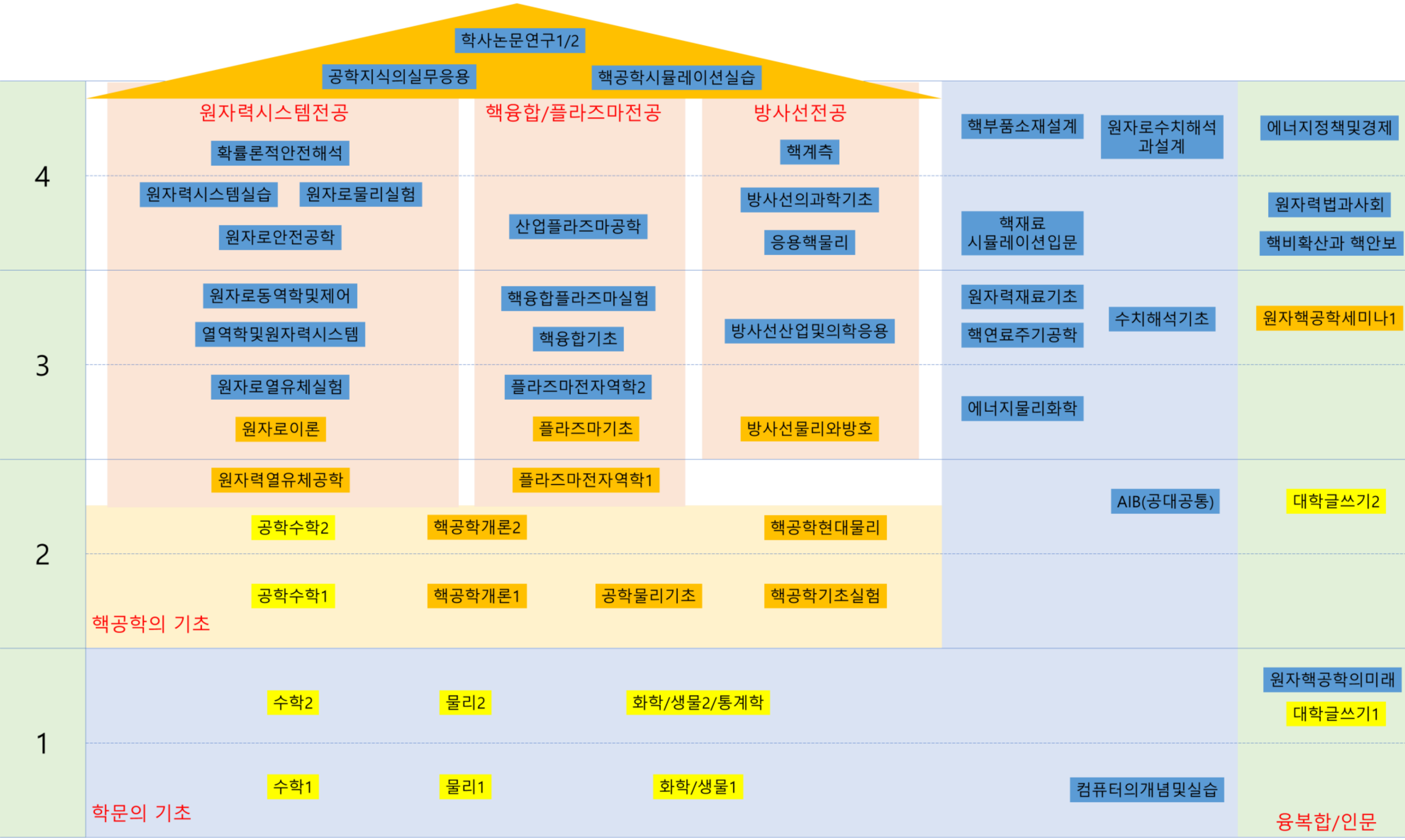
Textbooks and references

- **Radiation engineering**
  - J. Turner, Atoms, Radiation, and Radiation Detection, Wiley (2007)
  - A. Waltar, Radiation and Modern Life: Fulfilling Marie Curie's Dream, Prometheus Books (2004)
  - C. Grupen and M. Rodgers, Radioactivity and Radiation, Springer (2016)
  - Arthur Beiser, Concepts of Modern Physics (6th ed.), Mc-Graw Hill (2003)
  - N. Tsoulfanidid and S. Landsberger, Measurement and Detection of radiation, CRC Press (2015)

- **Plasma engineering**
  - F. Chen, Introduction to Plasma Physics and Controlled Fusion, Springer (2016)

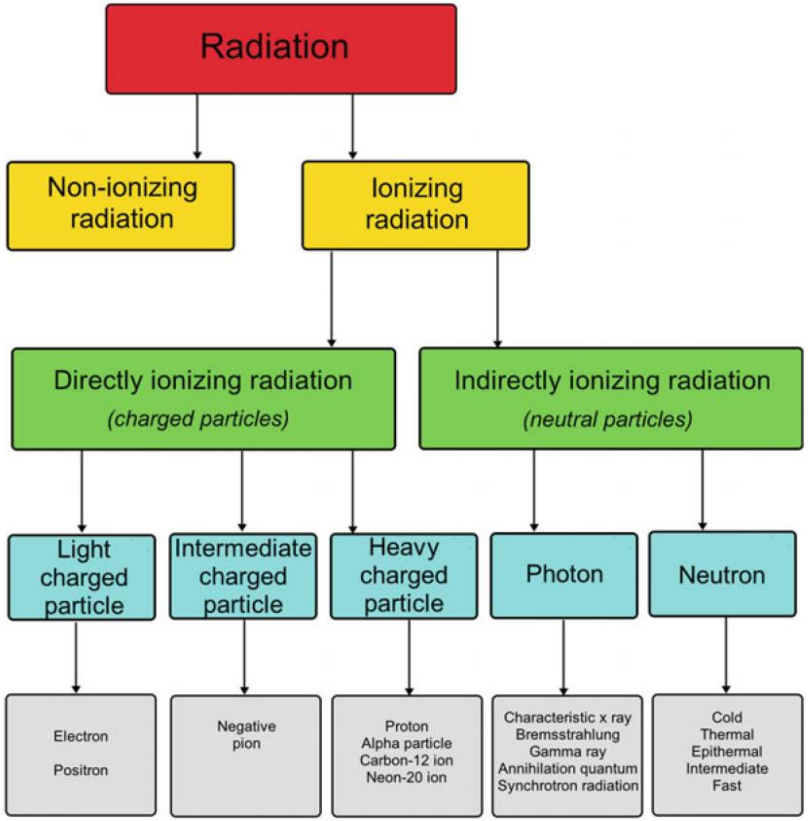
- **Fusion engineering**
  - G. McCracken and P. Stott, Fusion: The Energy of the Universe, Elsevier (2005)
  - F. Chen, An Indispensable Truth, Springer (2011)

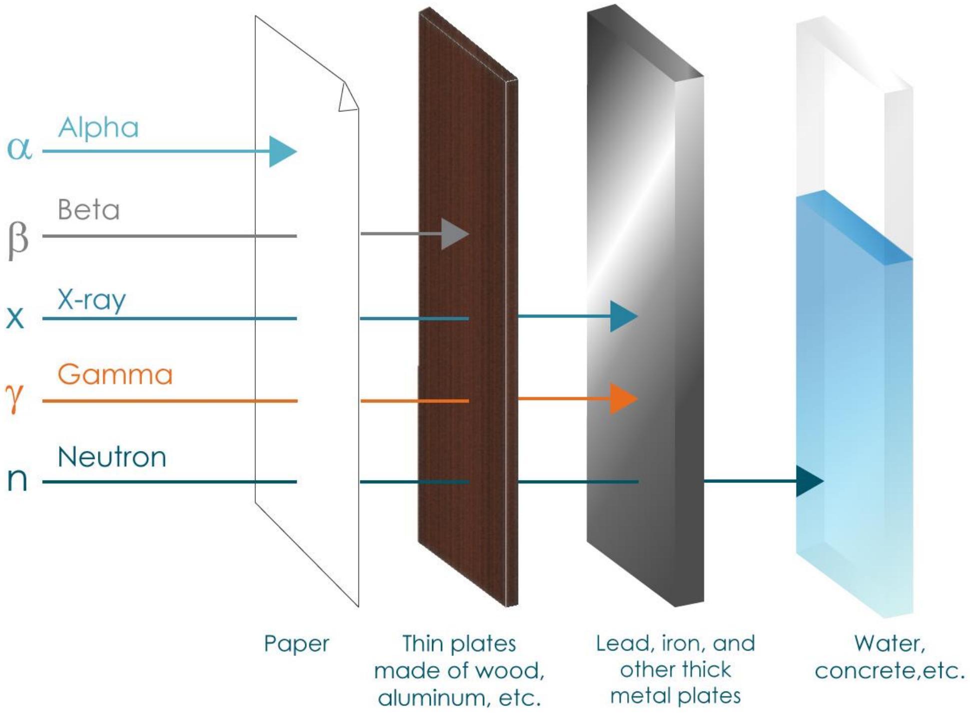
Curriculum


학사논문연구1/2
공학지식의실무응용
핵공학시뮬레이션실습
원자력시스템전공
핵융합/플라즈마전공
방사선전공
4
확률론적안전해석
핵계측
핵부품소재설계
원자로수치해석과설계
에너지정책및경제
원자력시스템실습
원자로물리실험
원자로안전공학
산업플라즈마공학
방사선의과학기초
응용핵물리
핵재료시뮬레이션입문
원자력법과사회
핵비확산과 핵안보
3
원자로동역학및제어
열역학및원자력시스템
핵융합플라즈마실험
핵융합기초
방사선산업및의학응용
원자력재료기초
핵연료주기공학
수치해석기초
원자핵공학세미나1
원자로열유체실험
원자로이론
플라즈마전자역학2
플라즈마기초
방사선물리와방호
에너지물리화학
2
원자력열유체공학
플라즈마전자역학1
AIB(공대공통)
대학글쓰기2
공학수학2
핵공학개론2
핵공학현대물리
공학수학1
핵공학개론1
공학물리기초
핵공학기초실험
핵공학의 기초
1
수학2
물리2
화학/생물2/통계학
원자핵공학의미래
대학글쓰기1
수학1
물리1
화학/생물1
컴퓨터의개념및실습
학문의 기초
융복합/인문

Classification of radiation

- Radiation: transportation of mass and energy through space





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Directly and Indirectly Ionizing Radiation

- Directly Ionizing Radiation: Comprises charged particles (electrons, protons, α-particles, heavy ions) that deposit energy in the absorber through a direct one-step process involving Coulomb interactions between the directly ionizing charged particle and orbital electrons of the atoms in the absorber.

- Indirectly Ionizing Radiation: Comprises neutral particles (photons such as x-rays and γ-rays, neutrons) that deposit energy in the absorber through a two-step process as follows:
  - In the first step a charged particle is released in the absorber (photons release either electrons or electron/positron pairs, neutrons release protons or heavier ions).
  - In the second step, the released charged particles deposit energy to the absorber through direct Coulomb interactions with orbital electrons of the atoms in the absorber.

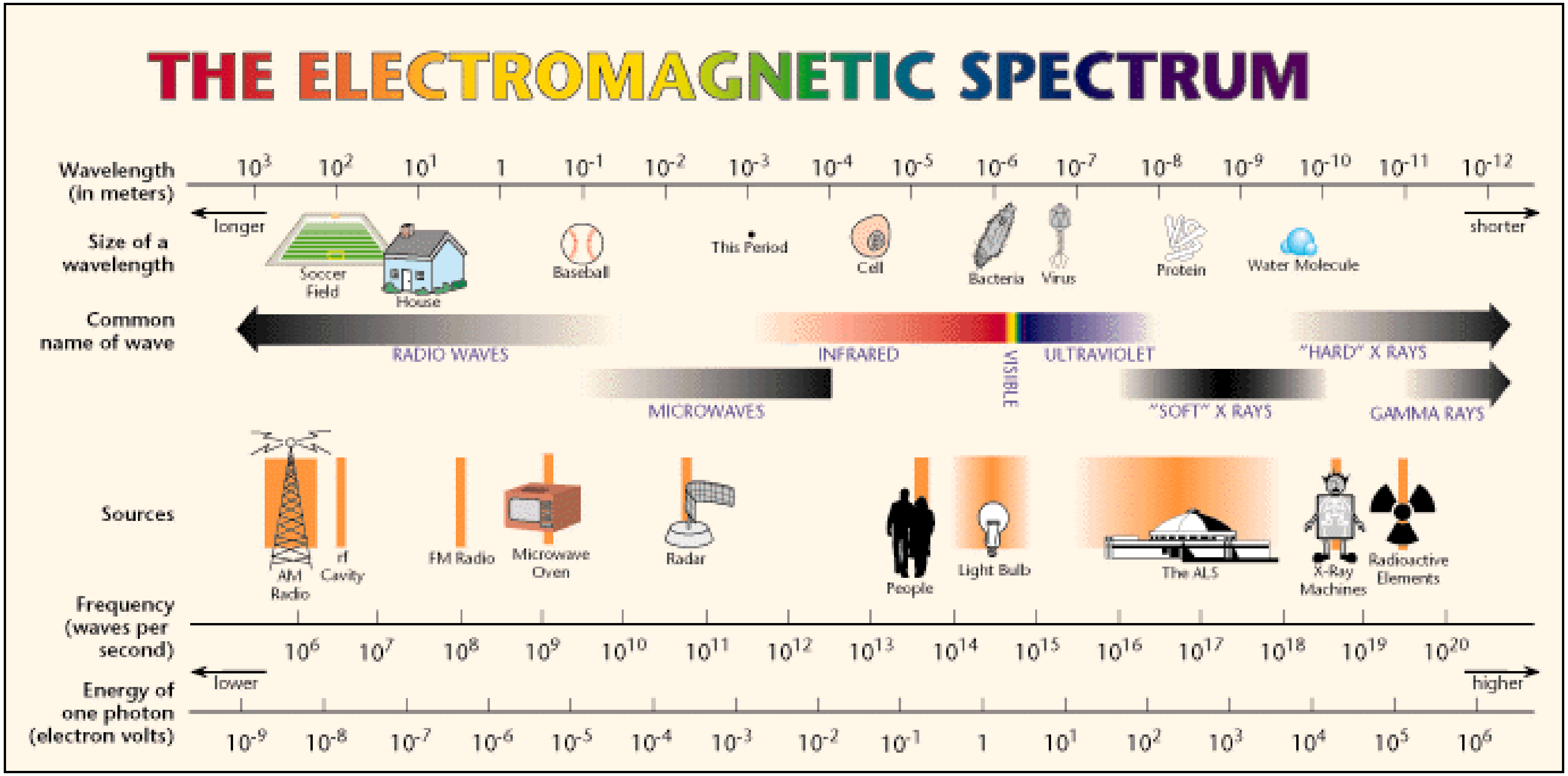
Photons

- A photon is regarded as a quantum of excitation in the underlying electromagnetic field.

$$E = h\nu = \frac{hc}{\lambda}$$

$$p = \frac{h\nu}{c} = \frac{h}{\lambda}$$

1 eV ~ 1,240 nm

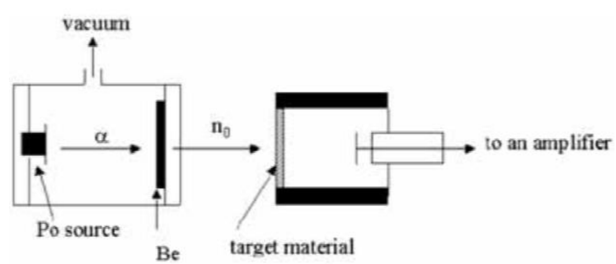


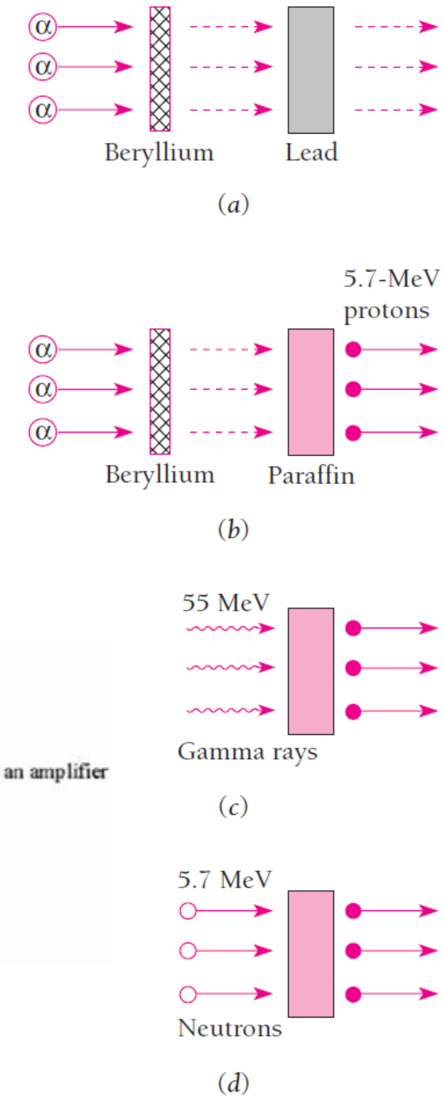
Chadwick's paper (Nature, 1932)

Possible Existence of a Neutron

It has been shown by Bothe and others that beryllium when bombarded by α-particles of polonium emits a radiation of great penetrating power, which has an absorption coefficient in lead of about 0·3 (cm.)$^{-1}$. Recently Mme. Curie-Joliot and M. Joliot found, when measuring the ionisation produced by this beryllium radiation in a vessel with a thin window, that the ionisation increased when matter containing hydrogen was placed in front of the window. The effect appeared to be due to the ejection of protons with velocities up to a maximum of nearly 3×10^9 cm. per sec. They suggested that the transference of energy to the proton was by a process similar to the Compton effect, and estimated that the beryllium radiation had a quantum energy of 50×10^6 electron volts.

I have made some experiments using the valve counter to examine the properties of this radiation excited in beryllium. The valve counter consists of a small ionisation chamber connected to an amplifier, and the sudden production of ions by the entry of a particle, such as a proton or α-particle, is recorded by the deflexion of an oscillograph. These experiments have shown that the radiation ejects particles from hydrogen, helium, lithium, beryllium, carbon, air, and argon. The particles ejected from hydrogen behave, as regards range and ionising power, like protons with speeds up to about $3{\cdot}2 \times 10^9$ cm. per sec. The particles from the other elements have a large ionising power, and appear to be in each case recoil atoms of the elements.





Chadwick's paper (Nature, 1932)

If we ascribe the ejection of the proton to a Compton recoil from a quantum of 52×10^6 electron volts, then the nitrogen recoil atom arising by a similar process should have an energy not greater than about 400,000 volts, should produce not more than about 10,000 ions, and have a range in air at N.T.P. of about 1·3 mm. Actually, some of the recoil atoms in nitrogen produce at least 30,000 ions. In collaboration with Dr. Feather, I have observed the recoil atoms in an expansion chamber, and their range, estimated visually, was sometimes as much as 3 mm. at N.T.P.

These results, and others I have obtained in the course of the work, are very difficult to explain on the assumption that the radiation from beryllium is a quantum radiation, if energy and momentum are to be conserved in the collisions. The difficulties disappear, however, if it be assumed that the radiation consists of particles of mass 1 and charge 0, or neutrons. The capture of the α-particle by the Be^9 nucleus may be supposed to result in the formation of a C^{12} nucleus and the emission of the neutron. From the energy relations of this process the velocity of the neutron emitted in the forward direction may well be about 3×10^9 cm. per sec. The collisions of this neutron with the atoms through which it passes give rise to the recoil atoms, and the observed energies of the recoil atoms are in fair agreement with this view. Moreover, I have observed that the protons ejected from hydrogen by the radiation emitted in the opposite direction to that of the exciting α-particle appear to have a much smaller range than those ejected by the forward radiation. This again receives a simple explanation on the neutron hypothesis.

If it be supposed that the radiation consists of quanta, then the capture of the α-particle by the Be^9 nucleus will form a C^{13} nucleus. The mass defect of C^{13} is known with sufficient accuracy to show that the energy of the quantum emitted in this process cannot be greater than about 14×10^6 volts. It is difficult to make such a quantum responsible for the effects observed.

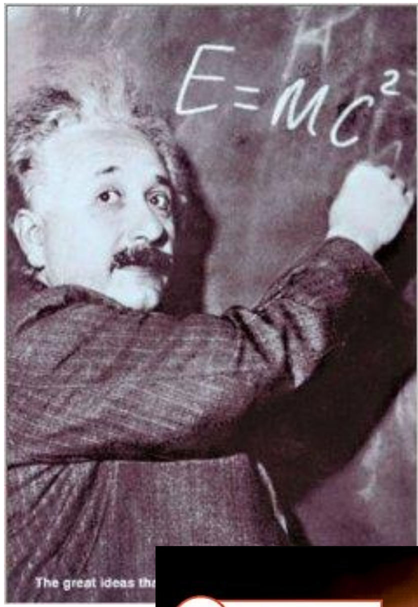
It is to be expected that many of the effects of a neutron in passing through matter should resemble those of a quantum of high energy, and it is not easy to reach the final decision between the two hypotheses. Up to the present, all the evidence is in favour of the neutron, while the quantum hypothesis can only be upheld if the conservation of energy and momentum be relinquished at some point.

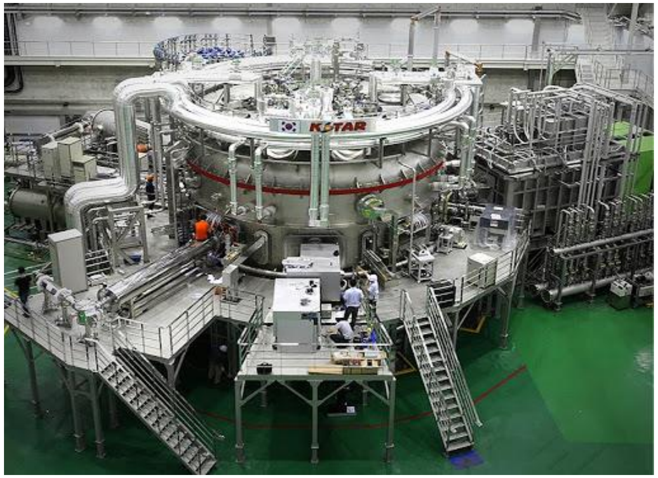
J. Chadwick.

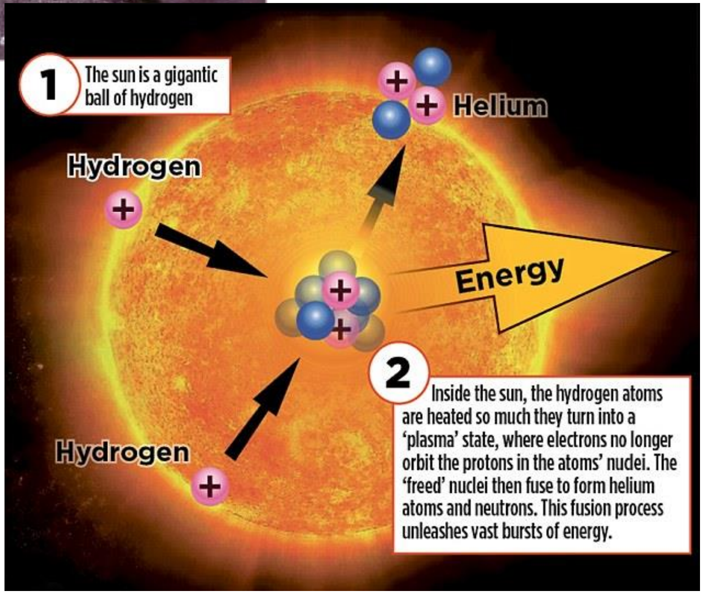
Cavendish Laboratory,
Cambridge, Feb. 17.

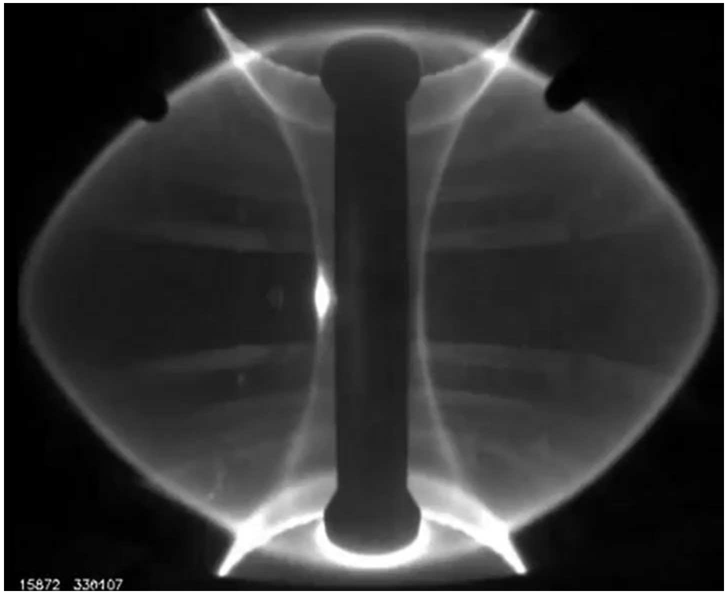
$$^{9}_{4}Be + \alpha \rightarrow {}^{12}_{6}C + n$$

The Sun's energy









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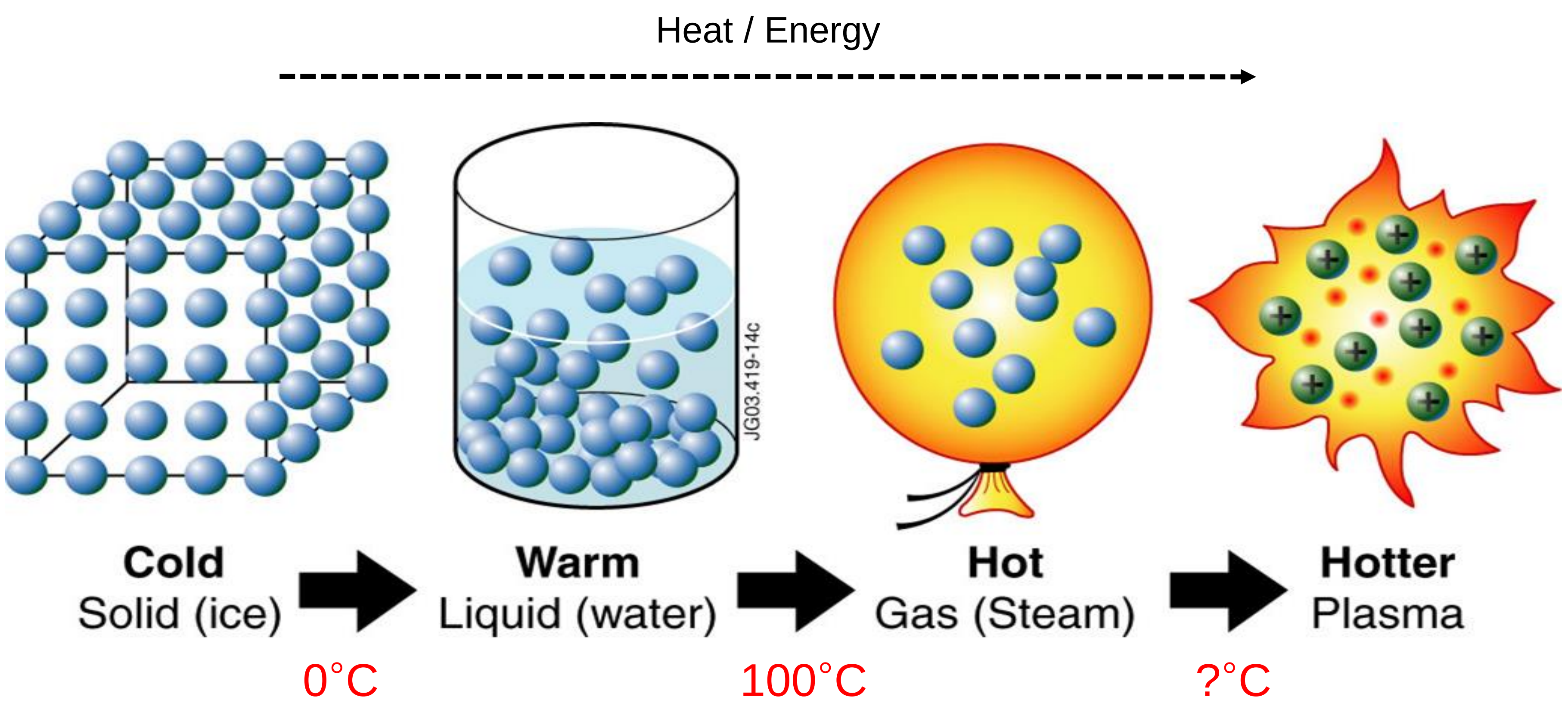
What is a plasma?



- A Plasma is quasi-neutral gas of charged and neutral particles which exhibits collective behavior. (Francis F. Chen)
- Plasma is a gas in which a certain portion of the particles are ionized. (Wikipedia)

Semiconductor manufacturing

Samsung Announces the Exynos 9825 SoC: First 7nm EUV Silicon Chip

by Andrei Frumusanu on August 6, 2019 9:30 PM EST