Plasma in Energy Research
-Fusion & Geothermal-

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Outline

Introduction

Fusion Energy

Geothermal Energy

Keep in mind

Introduction - Speaker's background

Employment

Oct 18 - Today	**Sci. assistant, Geothermal Energy and Geofluids group, ETH-Zurich**
Jan 19 - Today:	**Assistant lecturer, Physics Dept., Mansoura University, Egypt**
Dec 15 - Dec 18:	**Teaching assistant, Physics Dept., Mansoura University, Egypt**

Education

Oct 18 - Today:	**Ph.D, Institute of Geophysics, Earth Science Dept., ETH-Zurich**
Research area	Understanding the concept of pulsed plasma drilling for developing a viable contact-less deep drilling for Geothermal Energy to generate electricity.
Oct 16 - Jul 18:	**European MSc of Nuclear Fusion and Engineering Physics**
	`"--Great distinction--"`, Ghent University, Belgium
• Oct 16 - Jul 17:	Theoretical and practical courses at Stuttgart University & KIT, Germany.
• Sept 17 - Feb 18:	Courses in the University of Carlos III Madrid, Spain
• Feb 18 - Jul 18:	MSc thesis work as full time in CIEMAT, Madrid, Spain.
Thesis title:	Advanced neoclassical impurity transport modelling with its experimental comparison for TJ-II. Read the MSc thesis.
Sept 11 - Jul 15:	**BSc of Physics**, `"--Excellent with honors--", (1st Rank)`
	Faculty of Science, Mansoura University, Egypt
Thesis title:	Maxwell's Equations with Magnetic Charge in Fractional Form. Read

Introduction - Energy policy

In the 19$^{\text{th}}$ century:

- Fossil fuels reservoirs capacity.
- Consumption rate.

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Therefore, the required energy resources need to be available -fuel and the technology, environmental -low CO_2 emission, safe, and sustainable.

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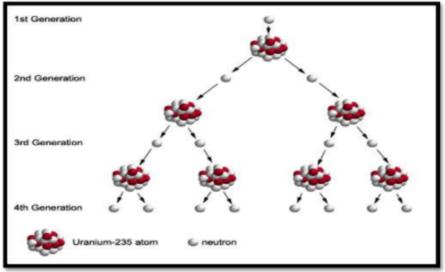
Fusion Energy

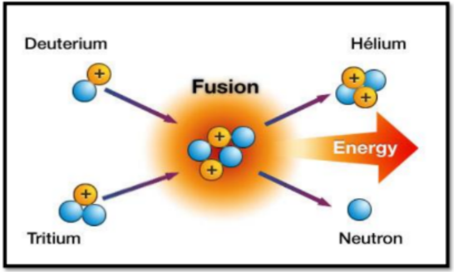
Fission



- Available tech.
- High capacity
- No CO2 emission

- Nuclear waste
- Fuel availability
- Security

Fusion



- Available Fuel.
- Higher capacity
- No CO2 emission

- No available technology. (We are working on)

Fusion Energy - Why?

2- High power density:

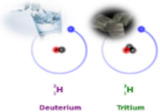
Power=18,000 kWh/year

1 Kg (Fuel)

4.5 hours

Burning coal
chemical reaction

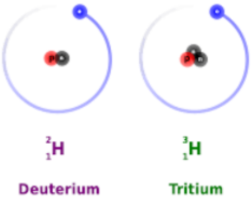
1323 years



5230 years

Fission and Fusion
Nuclear reaction

3- Available fuel (Only nuclear fusion)



Fusion Energy - Magnetic confinement

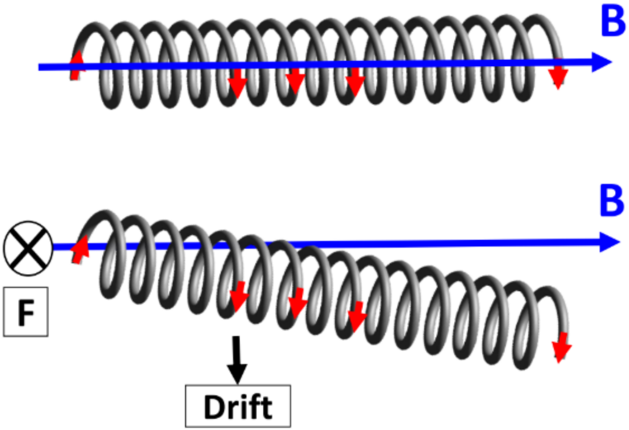
Equation of motion

$$m\frac{d\mathbf{v}}{dt} = q(\mathbf{v} \times \mathbf{B})$$

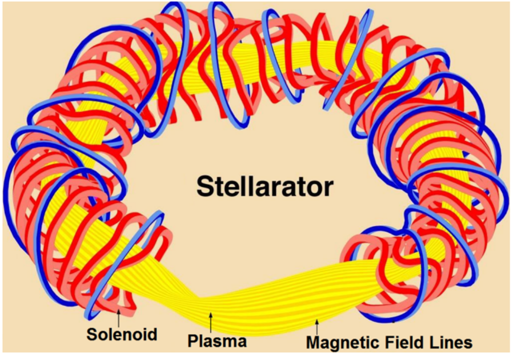
- m: mass
- v: velocity
- q: charge
- B: magnetic field

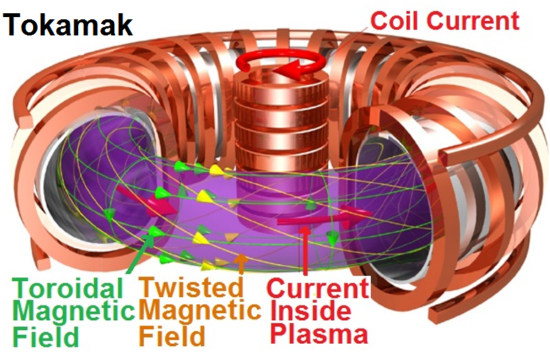
1- Drift velocity → $\mathbf{v}_F = \frac{\mathbf{F} \times \mathbf{B}}{qB^2}$

F: electric, centrifugal, B curvature, or gravitational force.

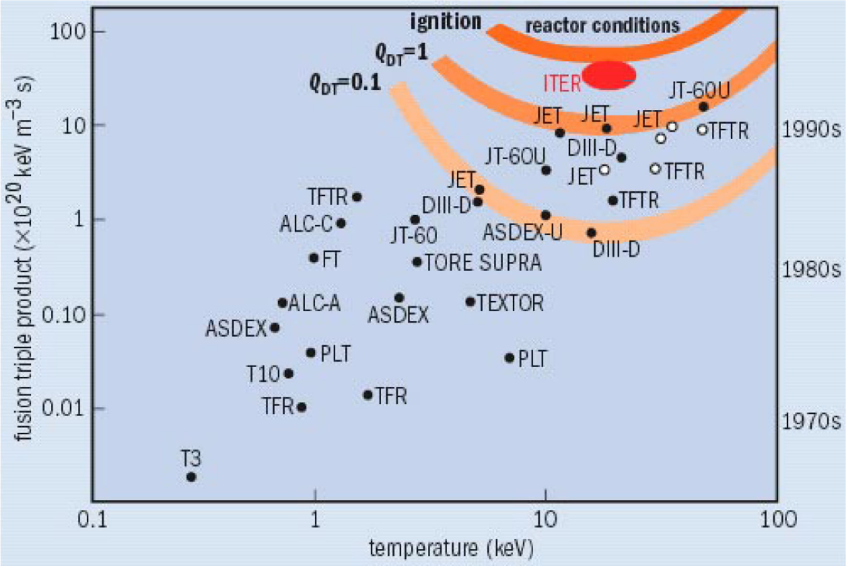


Fusion Energy - Tokamak vs stellerator





Fusion Energy - Triple product



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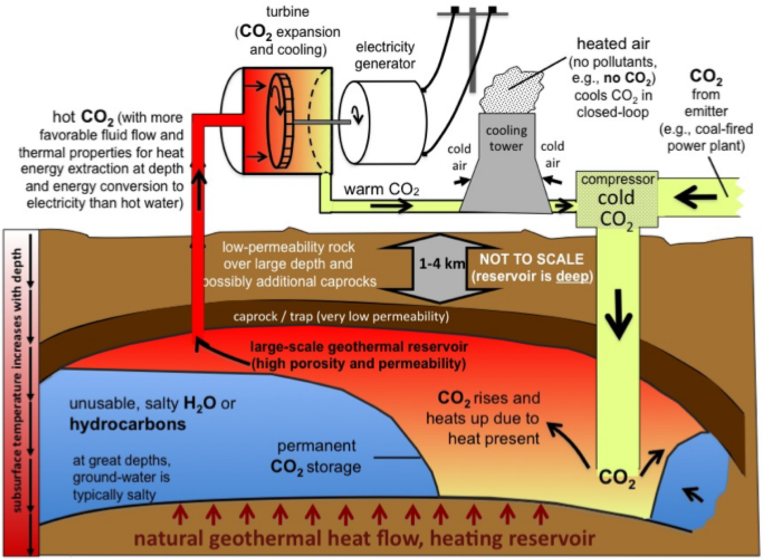


Geothermal Energy (Drilling)

- Expensive drilling cost that increases exponentially with depth because of the: (e.g: 38 M€ for two 3km wells St. Gallen project) [Overcoming Research Challenges for Geothermal Energy - EU Com., 2014]
  1. Low penetration rate 3-5 m/h in hard rocks.
  2. Low wear resistance in hard rocks ⇒ short life-time ⇒ increase the tripping cycles.
  3. Long tripping time.
- Small diameter of the production well because of several casing stages.

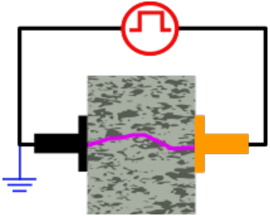
Plasma Pulse for Geo-Drilling (Advantages)

	Mechanical Rotary	PPGD	Reference
Tripping time [hour]	268	40	[Anders, et al. 2017]
Bit life time [hour]	50	350 (contactless)	[Anders, et al. 2017]
Frag. specific energy [J/cm^3]	400	200 (Tensile)	[Ushakov, et al. 2019]
Simultaneous casing	Not possible	Possible	[Hirschberg, et al. 2015]

Drilling cost formula:

$$\mathrm{C_D} = \frac{\mathrm{N_T} \times \mathrm{C_{Bit}} + \mathrm{C_{Rig}}\left[\mathrm{H}/\mathrm{ROP} + \mathrm{N_T} \times \mathrm{t_T}\right]}{\mathrm{H}}$$

Plasma Pulse Geo-Drilling (Concept)



No drilling fluid.

Pulse generator - High voltage electrode - Grounded electrode - Plasma channel

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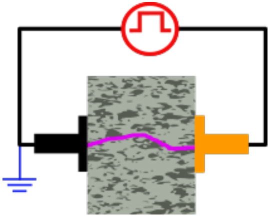

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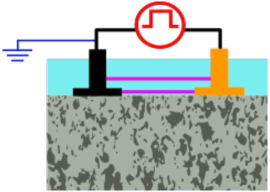

With drilling fluid
(normal pulse).

Pulse generator - High voltage electrode - Grounded electrode - Plasma channel - Drilling fluid (water)

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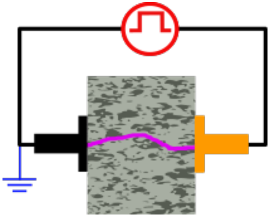

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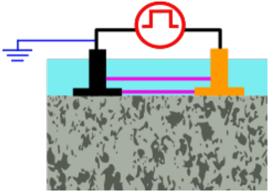

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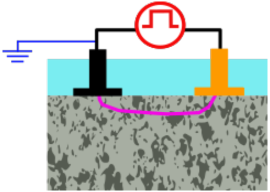


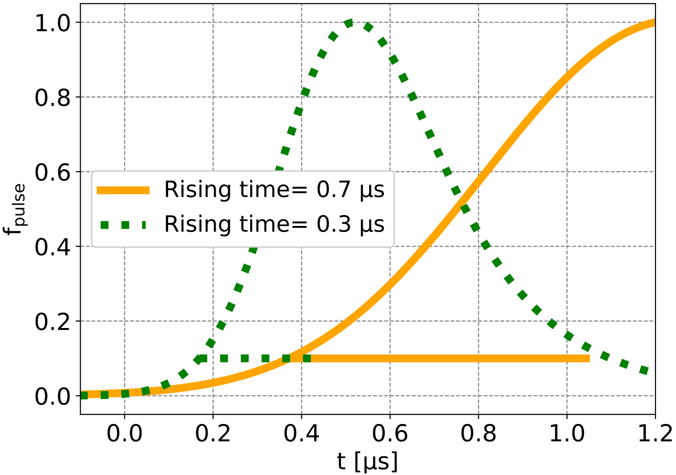
With drilling fluid (short pulse).

Pulse generator - High voltage electrode - Grounded electrode - Plasma channel - Drilling fluid (water)

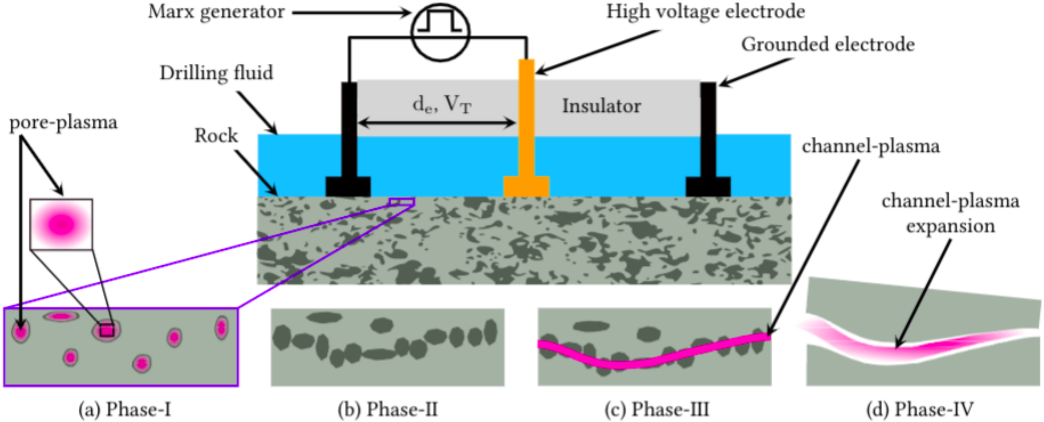
If the pulse rising time is less than 0.5 μs, the dielectric strength of the rock will become less than the dielectric strength of the drilling fluid (water).

[Vorobev, et al. 1961 (in Russian) as cited in Boev, et al., 1997, Ushakov, et al. 2019].

Plasma-Pulse Geo-Drilling (High voltage short pulse)



Plasma-Pulse Geo-Drilling (Damage phases)



Plasma-Pulse Geo-Drilling (Plasma formation in pores)

Continuity equation:

$$\frac{\partial \mathrm{n_s}}{\partial \mathrm{t}} + \frac{\partial \Gamma_\mathrm{s}}{\partial \mathrm{x}} = \mathrm{S_i} \tag{1}$$

Flux & source term:

$$\Gamma_\mathrm{s} = \mathrm{q}\mu_\mathrm{s}\mathrm{E}\mathrm{n_s} - \mathrm{D_s}\frac{\partial \mathrm{n_s}}{\partial \mathrm{x}} \ \& \ \mathrm{S_i} = \alpha_\mathrm{i}\left(\mathrm{E}, \epsilon\right)\Gamma_\mathrm{e} \tag{2}$$

Momentum equation:

$$\frac{\partial\left(\mathrm{n_e}\epsilon\right)}{\partial \mathrm{t}} + \frac{\partial \Gamma_\epsilon}{\partial \mathrm{x}} = -\mathrm{e}\Gamma_\mathrm{e}\mathrm{E} - \Gamma_\mathrm{e}\left(\alpha_\mathrm{i}\epsilon_\mathrm{i} + \alpha_\mathrm{ex}\epsilon_\mathrm{ex} + 3\frac{\mathrm{m_e}}{\mathrm{m_i}}\alpha_\mathrm{e1}\mathrm{T_e}\right) \tag{3}$$

Poission equation:

$$\mathrm{E} = -\frac{\partial \Phi}{\partial \mathrm{x}} \tag{4}$$

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Thank you for your attention!

Should you have any question or need reference, please write to me:
m.ezzat@erdw.ethz.ch