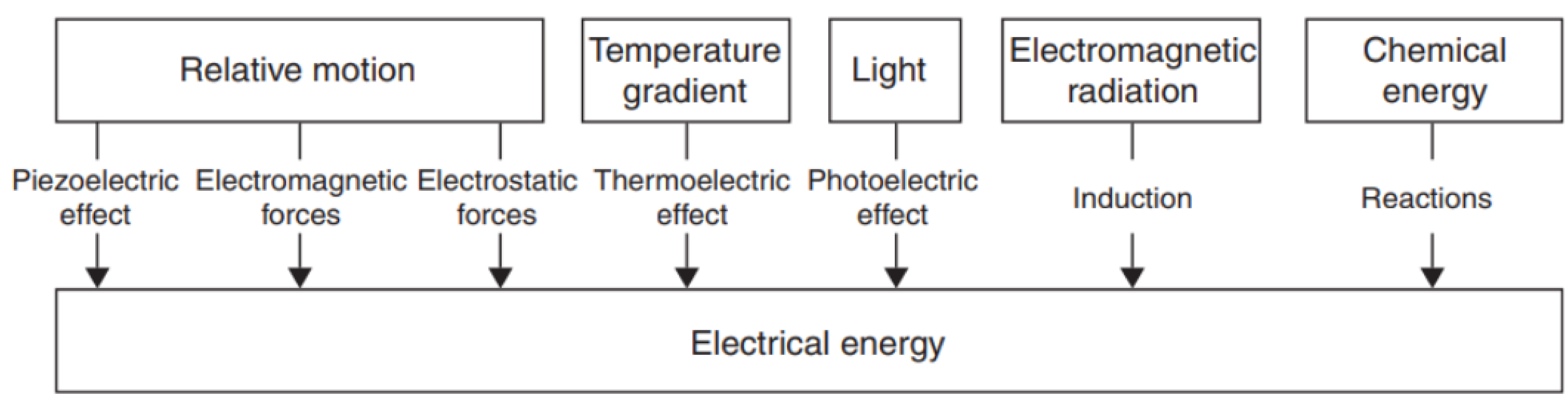
- ME (Mechanical-to elec) -> turbine → Piezo, electro
- CE (Chemical..) -> battery, fuel cell
- SE (Solar..) -> PV/SH
- RFE (Radio Frequency..) -> ambient electromagnetic energy to elec
- TE (Thermal..) -> TEG

- Direct force
- Inertial force

- Seebeck : $\Delta T \to e^-$
- Peltier : $e^- \to \Delta T$

- Resonant
- Non-resonant

- Battery
- Fuel cell



$$U = \bar{Q} + \bar{\omega}$$

internal energy, heat, work

$\bar{Q} \to Q = \int C \, dT \to C \cdot \Delta T$

$\bar{\omega} \to \omega = P \cdot \Delta V$

$\Delta V = 0 \to$ no work

$$ZT = \left(S^2\sigma/\kappa_e + \kappa_L\right) T$$

$$\eta = \frac{P}{Q} = \frac{\Delta T}{T_H}\left(\frac{\sqrt{1+\overline{ZT}}-1}{\sqrt{1+\overline{ZT}}+\frac{T_C}{T_H}}\right)$$

$$P_{max} = \frac{(S\Delta T)^2}{4R} = \frac{(S\Delta T)^2}{4\rho}\frac{A}{L}$$

$$P_{max} = \frac{V_{oc}^{\;2}}{4R} = \frac{\left(n(|S_p| + |S_n|)\Delta T\right)^2}{4R}$$

The output power of the device (P_L) can be expressed as:

$$P_L = P = \frac{V_L^{\;2}}{R_L} = \frac{\left(\frac{R_L V_{oc}}{R + R_L}\right)^2}{R_L}$$

$$P_{max} = \frac{V_{oc}^{\;2}}{4R} = \frac{\left(n(|S_p| + |S_n|)\Delta T\right)^2}{4R}$$

Gas Law Formula		
Gas Law	**Formula**	**Description**
Boyle's Law	$P_1V_1 = P_2V_2$	At constant *T*, as pressure increases, volume decreases.
Charles' Law	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$	At constant P, as volume increases, temperature increases.
Gay-Lussac's Law	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$	At constant V, as pressure increases, temperature increases.
Combined Law	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$	Obtained by combining Boyle's Law, Charles' Law and Gay-Lussac's Law.
Ideal Gas Law	$PV = nRT$	$\rho = PM/RT$ → molar mass $\frac{m}{n}$
V = volume in dm^3 (litre) T = temperature in K	P = pressure in kPa n = number of moles	R = ideal gas constant 0.0821 $\frac{L \cdot atm}{mol \cdot K}$

Avogadro $\frac{V_1}{n_1} = \frac{V_2}{n_2}$

Carnot eff

$$\eta_c = \frac{T_h - T_c}{T_h} \cdot T_c$$

Thermal eff

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

$$\text{Power} = \frac{1}{2}\rho A U^3 = \frac{1}{2}\rho\pi R^2 U^3$$

absorbed solar radiation (S) using:

$$S = G_T \times (\tau\alpha)_{av}$$

useful energy gain ($\dot{Q}_u$) using:

$$\dot{Q}_u = A_c \times F_R \times [S - U_L(T_{in} - T_{amb})]$$

e outlet temperature (T_{out}) of the working fluid using:

$$T_{out} = T_{in} + \frac{\dot{Q}_u}{\dot{m}c_p}$$

thermal efficiency (η) of the collector:

$$\eta = \frac{\dot{Q}_u}{A_c G_T}$$

$$C_{geo} = \frac{A_a}{A_r}$$

$$U_L = \dot{Q}_s = \eta_0 \times A_a \times I_0 \times \text{heat transfer efficiency}$$

Friis Eq

$$P_R = P_T \cdot G_T \cdot G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

T : Transmitted
R : recieved
P : power (W)
G : Antenna gains
d : distance

Thermal

- Thermal E → total Kinetic E of particle/molecules / vibration, rotational, move/transational
- Temp → avg kin. E per particle
- Heat E → amount of Thermal E transferred

Law of thermodyn

- 0^{th} → temp.
- 1^{st} → $U = \bar{Q} + \bar{W}$ (internal energy, heat, work)
  - $Q = \int C\,dT \Rightarrow C\,\Delta T$
  - $W = P.\Delta V$; $\Delta V = 0$ → no work
- 2^{nd} → phases (solid → liq → gas) teratur, chaotic
- 3^{rd} → $T = 0$ K → absolute zero entropy

System type:
- Open → mass & E transfer
- closed → only E transfer
- isolated → no transfer

between syst & surrounding

path dependent properties?

Approach:
- macro → P.T.V,n.m
- micro

state

$V = f(n, p, T)$ or $p = g(n, V, T)$

3 H_2 (g, 1 bar, 100 °C)

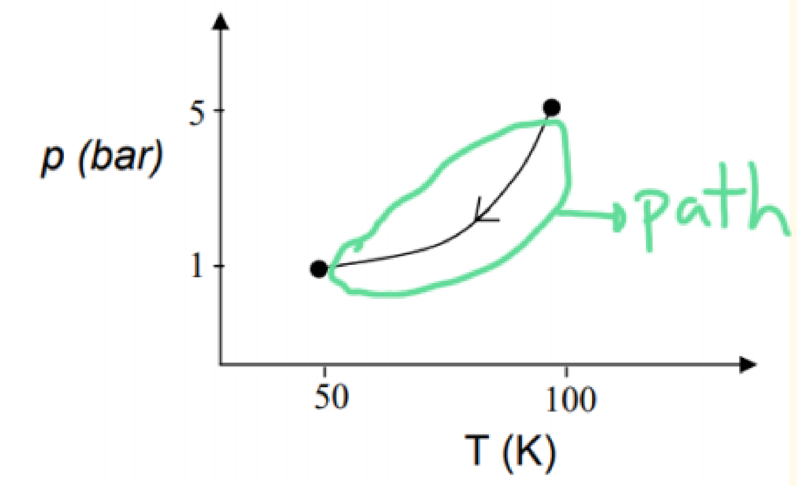
3 moles (n=3) | gas | p=1 bar | T=100 °C

Change of state or Transformation

❖Notation:

$\underbrace{3\ H_2\ (g,\ 5\ \text{bar},\ 100\ °C)}_{\textit{initial state}} = \underbrace{3\ H_2\ (g,\ 1\ \text{bar},\ 50\ °C)}_{\textit{final state}}$

❖Path: Sequence of intermediate states



Process: Describes the Path
- ❖Reversible (always in Equilibrium) water ⟷ ice
- ❖Irreversible (defines direction of time) wood → ash
- ❖Adiabatic (no heat transfer between system and surroundings) → $Q = 0$
- ❖Isobaric (constant pressure) → $W + Q$
- ❖Isothermal (constant temperature) $\Delta T = 0$ → $Q = 0$
- ❖Isochoric (constant volume) → $\Delta V = 0$ → $W = 0$

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V = volume in dm^3 (Litre) T = temperature in K	P = pressure in kPa n = number of moles	R = ideal gas constant $0.0821 \frac{L \cdot atm}{mol \cdot K}$

Avogadro $\frac{V_1}{n_1} = \frac{V_2}{n_2}$

① 2.027 atm

② 12.93 L

$\rho = \frac{m}{V} \to P = \frac{F}{A}$

$\frac{F}{V \cdot A}$

Thermal E

Parameter → figure of merit

$$ZT = \left(S^2\sigma/\kappa_e + \kappa_L\right)T$$

└→ efficiency

$$\eta = \frac{P}{Q} = \frac{\Delta T}{T_H}\left(\frac{\sqrt{1+\overline{ZT}}-1}{\sqrt{1+\overline{ZT}}+\frac{T_C}{T_H}}\right)$$

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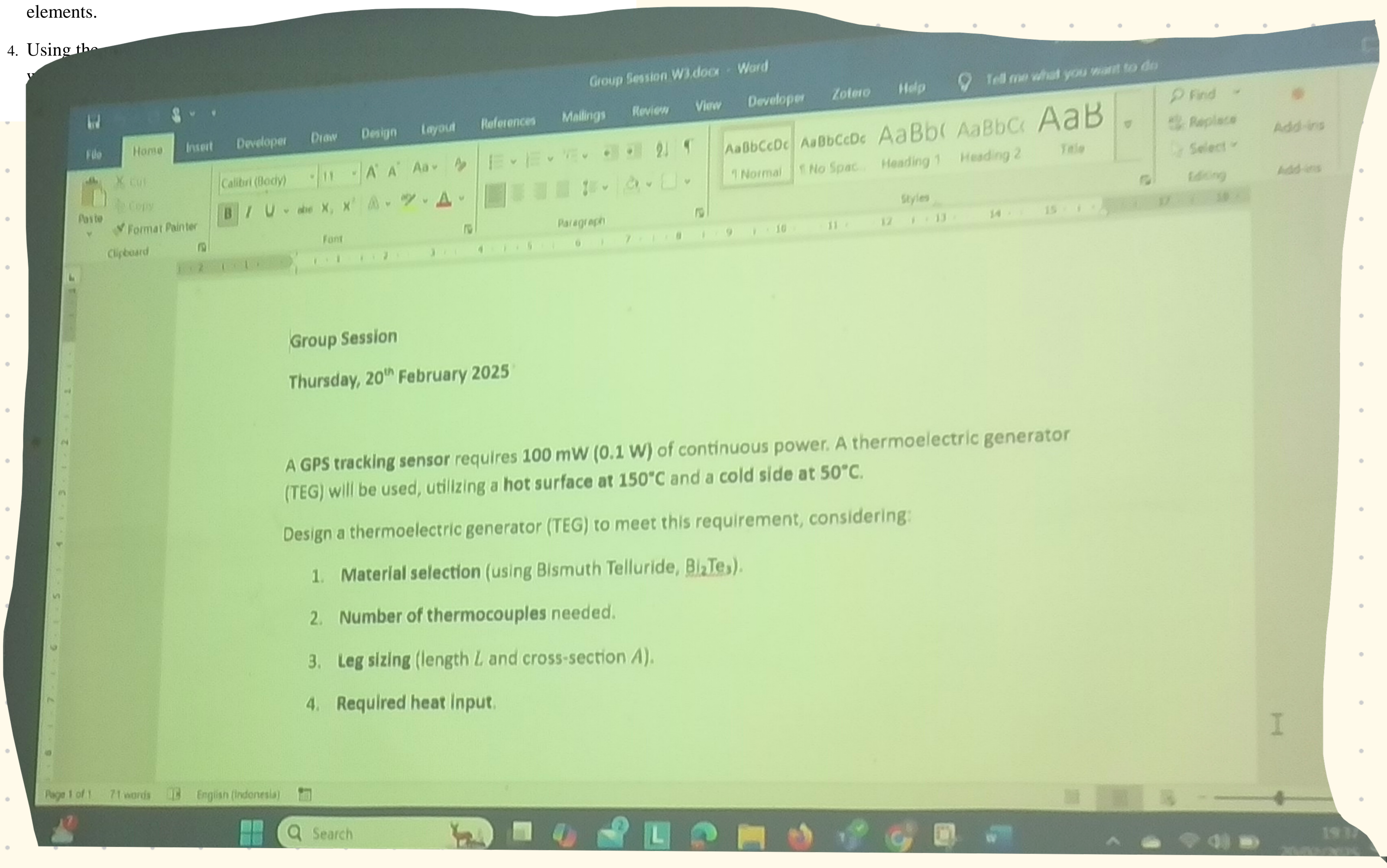
Design a small thermoelectric generator to power a wearable health monitoring device using the temperature difference between the human body and the ambient environment.

Example calculation: Assume the body temperature is 37°C and the ambient temperature is 20°C. Design a TEG with a footprint of 5 cm^2 and a thickness of 5 mm to generate sufficient power to run the wearable device.

1. To design the TEG, we need to consider the following factors: Temperature difference: ΔT = 37°C - 20°C = 17°C
2. Thermoelectric material properties: Seebeck coefficient, electrical resistivity, thermal conductivity
3. Geometric dimensions: cross-sectional area and length of the thermoelectric elements.
4. Using th



Group Session

Thursday, 20th February 2025

A **GPS tracking sensor** requires **100 mW (0.1 W)** of continuous power. A thermoelectric generator (TEG) will be used, utilizing a **hot surface at 150°C** and a **cold side at 50°C**.

Design a thermoelectric generator (TEG) to meet this requirement, considering:

1. **Material selection** (using Bismuth Telluride, Bi_2Te_3).
2. **Number of thermocouples** needed.
3. **Leg sizing** (length L and cross-section A).
4. **Required heat input**.

Sample calculation: Consider a TEG with a temperature difference of 200°C, a cross-sectional area of 10 cm², and a length of 2 cm. Assume the thermoelectric material has a Seebeck coefficient of 200 µV/K, an electrical resistivity of 1 × 10^-5 Ω·m, and a thermal conductivity of 1.5 W/m·K. Calculate the power output of the TEG (Bell, 2008) (Yazawa & Shakouri, 2011).

S	0.0002	**P**	**2**
T	200		
A	0.001		
L	0.02		
elec rest	0.00001		
k	1.5		

```
=(B22*B23)^2*B24/(4*B26*B25)
```

Determine the conversion efficiency of a thermoelectric generator given the material's figure of merit and the temperature difference between the hot and cold sides.

Consider a thermoelectric material with a figure of merit, *ZT*, of 1.0. The hot-side temperature is 600 K, and the cold-side temperature is 300 K. Calculate the maximum theoretical efficiency of a thermoelectric generator using this material.

$$\eta = \frac{P}{Q} = \frac{\Delta T}{T_H}\left(\frac{\sqrt{1+\overline{ZT}}-1}{\sqrt{1+\overline{ZT}}+\frac{T_C}{T_H}}\right)$$

ZT	1	Eff	0.10819
Th	600	Carnot	0.5
Tc	300		

```
=((B30-B31)/B30)*(((1+B29)^(1/2)-1)/((1+B29)^(1/2)+(B31/B30))
```

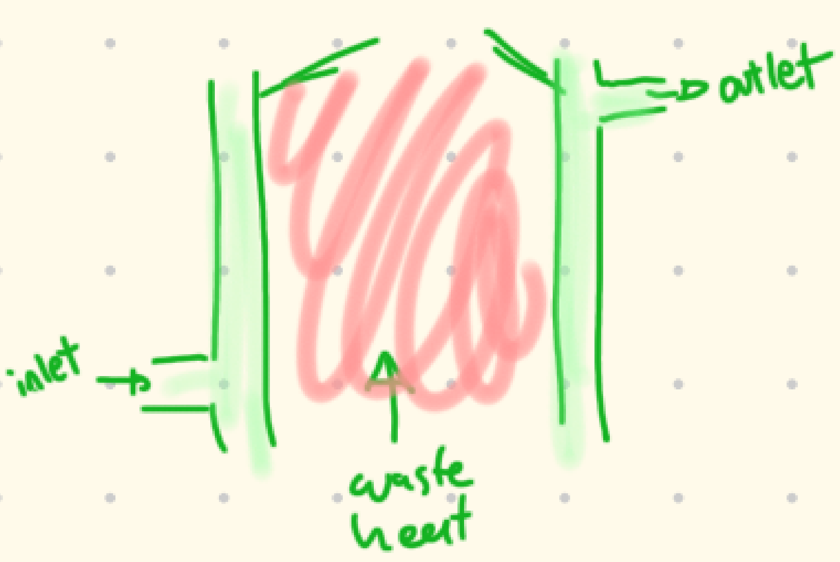
WEEK 4

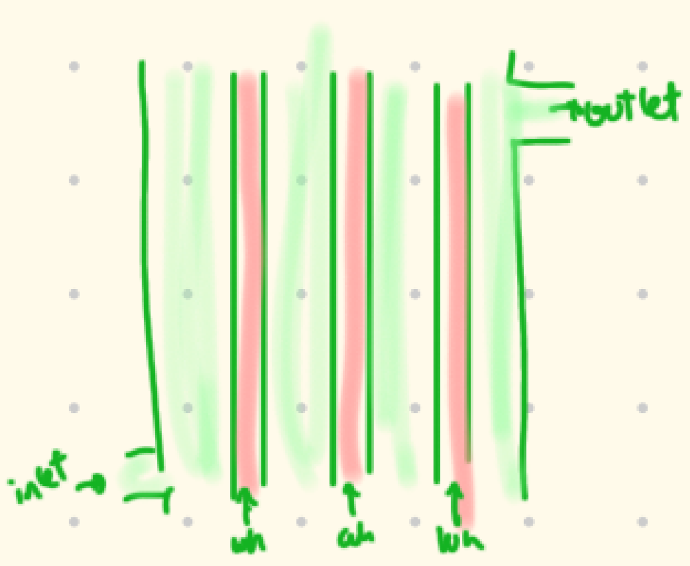
Type
- High
- med
- low

Tech
- Heat ex
- TEG
- Org. rankine cycle
- TPV
- Piezo electric gen

Heat exc

- Recuperator — area & Time
  - radiation
  - convective





- Regeneration
- Organic Rankine cycle

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_e - h_i$$

Pump ($q = 0$): $$w_{pump,in} = h_2 - h_1$$

or,

$$w_{pump,in} = v(P_2 - P_1)$$

where

$$h_1 = h_{f\,@\,P_1} \quad \text{and} \quad v \cong v_1 = v_{f\,@\,P_1}$$

Boiler ($w = 0$): $$q_{in} = h_3 - h_2$$

Turbine ($q = 0$): $$w_{turb,out} = h_3 - h_4$$

Condenser ($w = 0$): $$q_{out} = h_4 - h_1$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

$$w_{net} = q_{in} - q_{out} = w_{turb,out} - w_{pump,in}$$

Solar Thermal

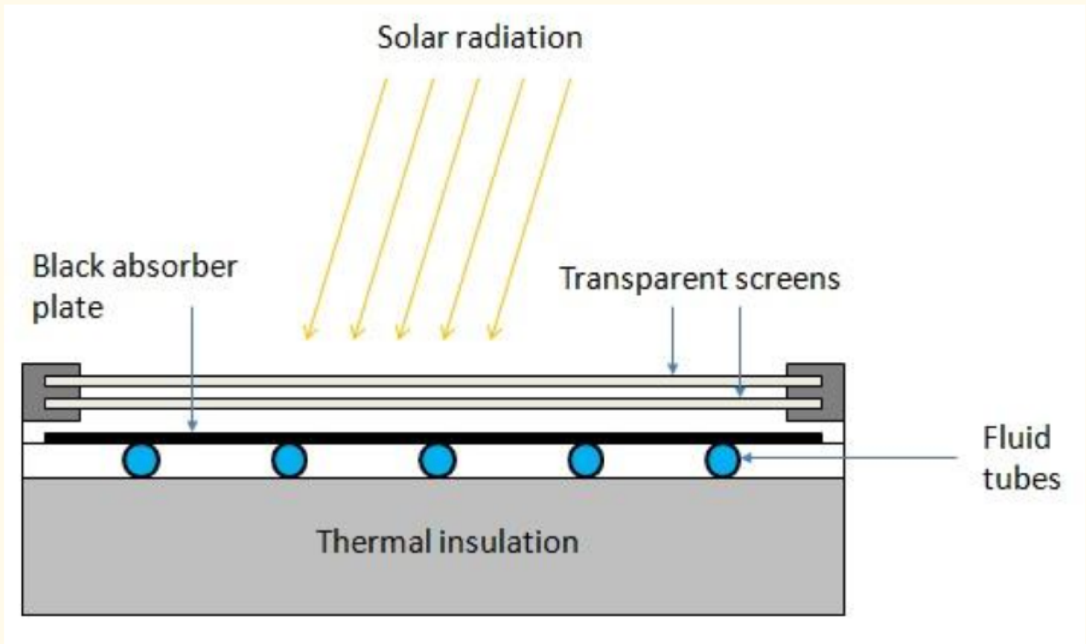
ST Application = heating, elect(processed w/ TEH)

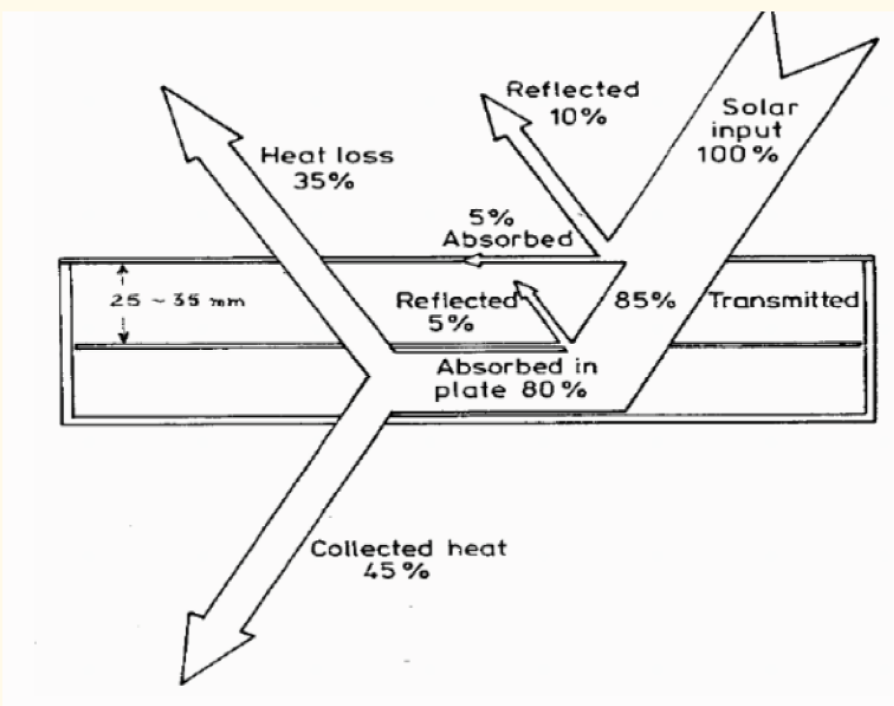
mechanism
- conduction → solid
- convection → fluid
- radiation → no medium

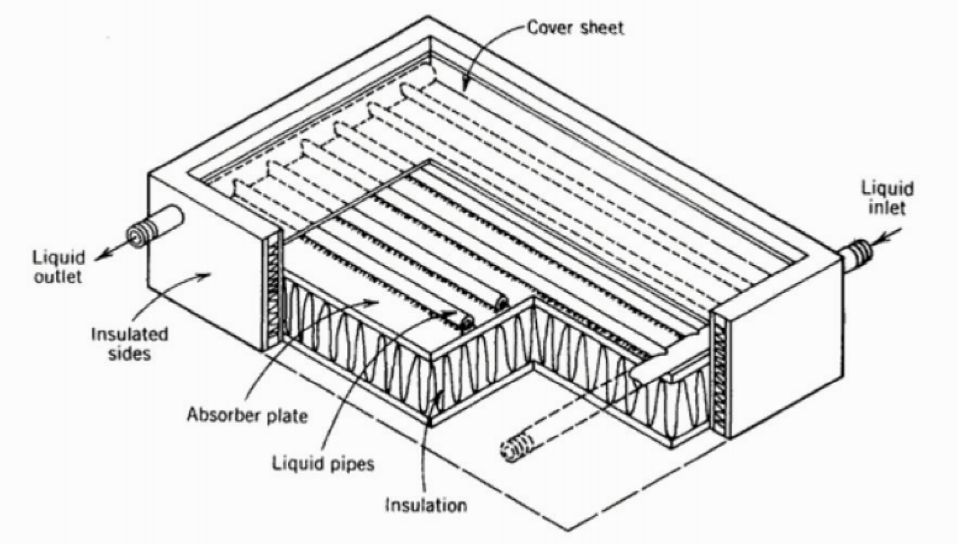
Type
- w/o consentration → surface colc, tube coled.
  → 80 - 150°C
- concentrated → 300 - 800 °C

Flat Plate Collectors (FPC)

• in winter, usually 'Anti-Freeze Agent' is added so the working fluid will not freeze up.







Wind & Hydro

Wind variability properties

Turbulence intensity
Turbulent kinetic energy
Autocorrelation
Integral time scale/length scale
Power spectral density function

+ wind speed & direction

- Wind turbine [illegible]

- vortex-induced vibratiom
- galloping (transverse & wake)
- flutter
- turbulence-induced vibration

Hydro

- ballistic electrostatic: droplet's inertia to electricity

- Small-Scale Windmill and Wind Turbine.
- Energy Harvesters Based on Vortex-Induced Vibrations
- Energy Harvesters Based on Galloping
- Energy Harvesters Based on Flutter (Model vs Cross-flow)
-
-

Technology apa aja?

Pilih 1 tech, jelaskan ~~tekil~~ detail