LECTURE 10

Machines that Store and Transfer Energy

Thermodynamics and Energy Conversion

2.000 Thermodynamics

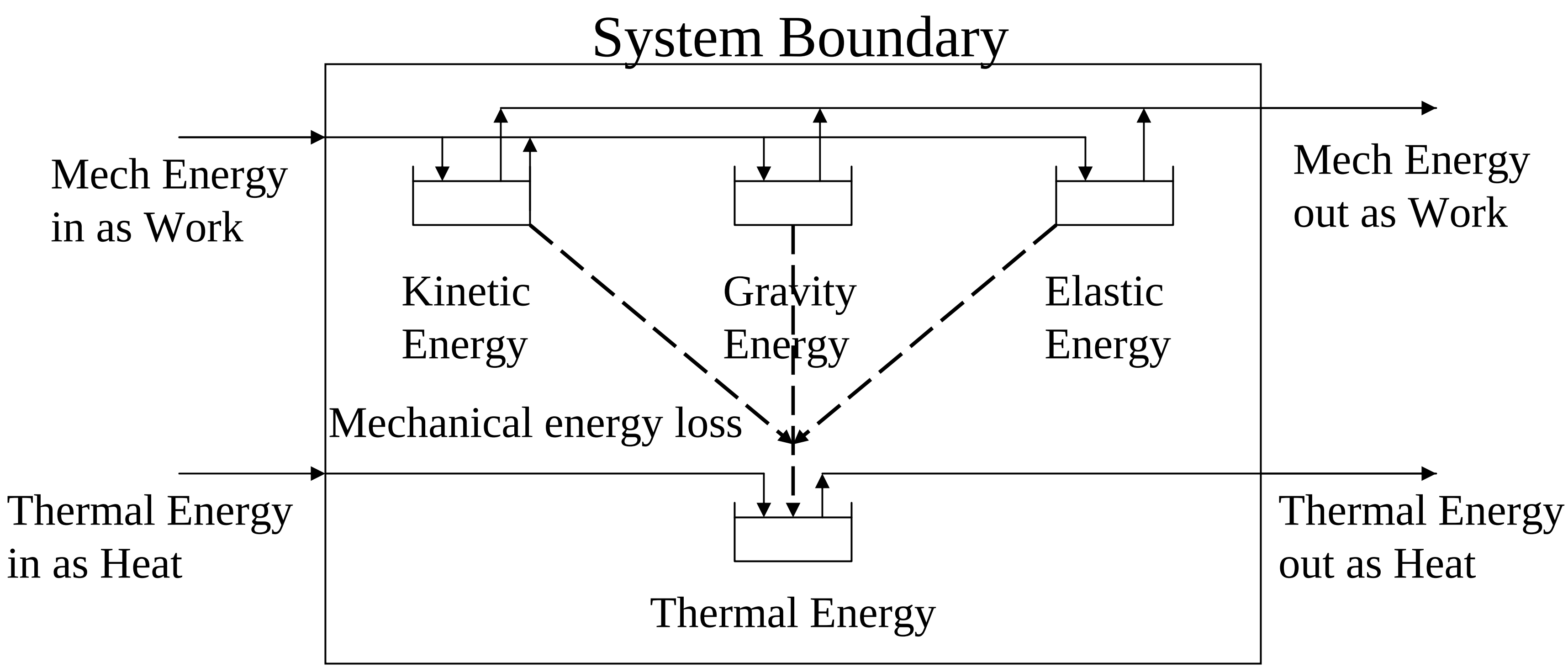
Topics of today's lecture:

- Marty: Project I questions/answers
- Joe: Thermodynamics and machinery

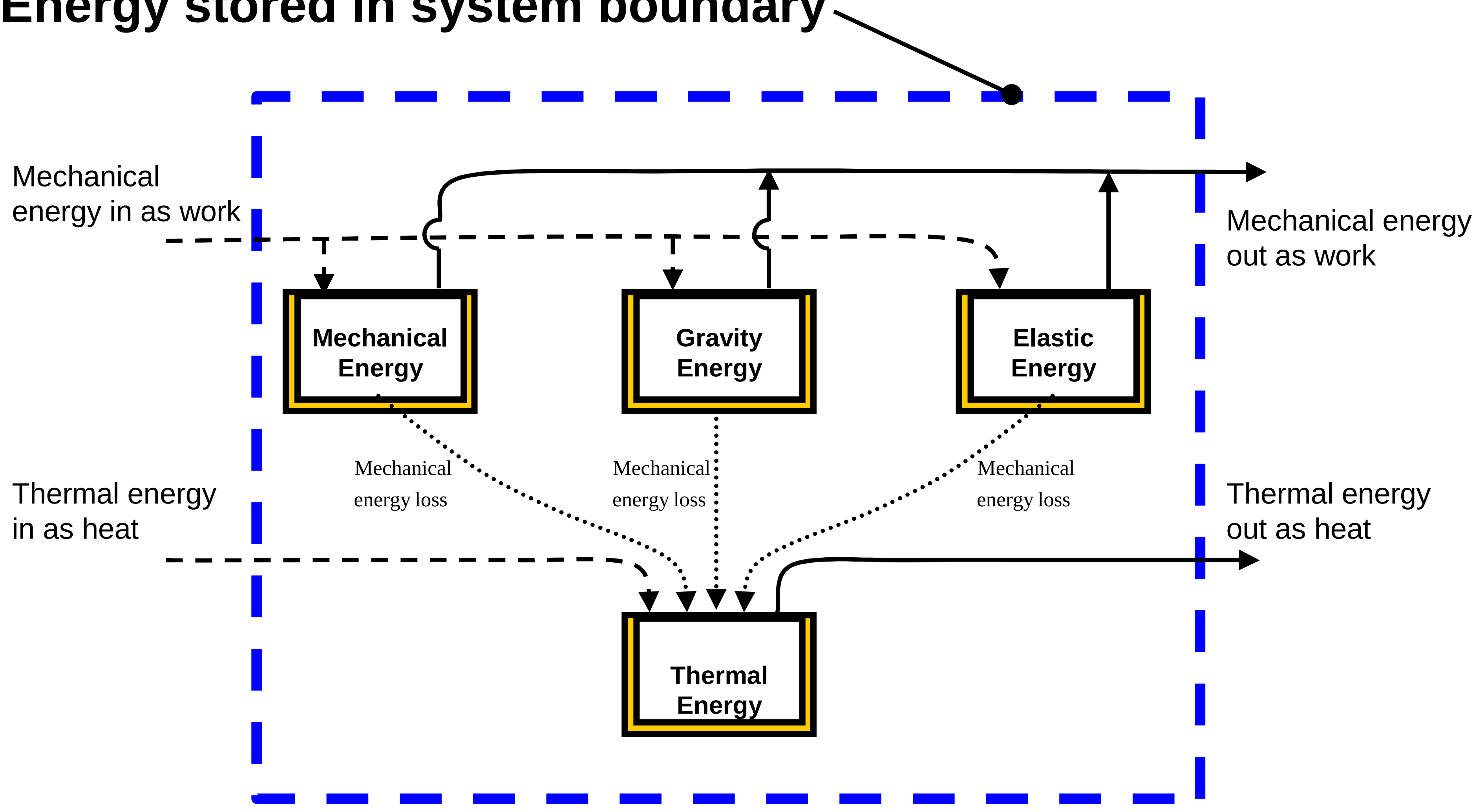
Simple energy concepts

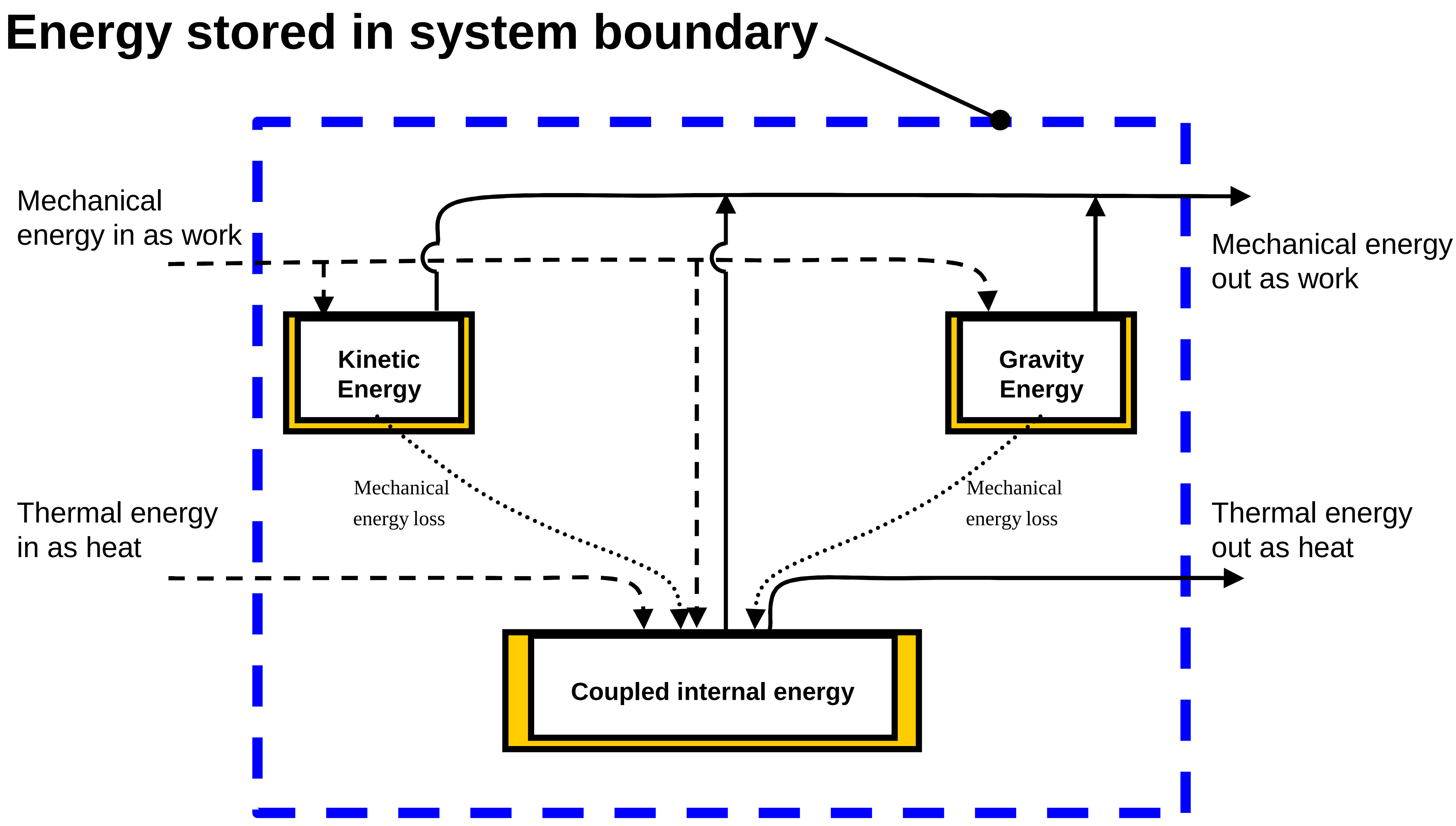
Energy is stored in separate boxes

Thermal energy can only go to a colder system by heat transfer



Energy stored in system boundary




Energy stored in system boundary
Mechanical energy in as work
Thermal energy in as heat
Kinetic Energy
Gravity Energy
Mechanical energy loss
Mechanical energy loss
Mechanical energy out as work
Thermal energy out as heat
Coupled internal energy

Thermodynamic energy concepts

Energy in by heat transfer is stored in same box as energy in by:

- **F dx = p A dx = p dv**

No separate thermal energy storage

Energy transfers

Work is energy or power transferred by:

- $F\,dx = p\,A\,dx = p\,dv$

Heat is energy transferred as the result of a temperature difference

Energy storage

Non-thermodynamic systems have separate energy storage -- Uncoupled system.

Thermodynamic systems have coupled energy storage -- Internal energy in thermodynamics.

Thermal expansion is evidence of coupled storage:

- **Solids have small thermal expansion - small coupling**
- **Gases have large expansion - strong coupling**
- **Boiling liquids have very large expansion - very large coupling**

Energy for a gas

As a result of the coupling energy and thus temperature of a gas can be increased or decreased by both work and heat.

Work out can decrease the temperature of a gas without a heat. This is not possible with uncoupled energy storage.

Energy can go in as heat and come out as work -- Energy conversion. This is not possible with uncoupled energy storage.

With work in, heat can go in at a low temperature and come out at a high temperature -- Heat pumping.

Piston cylinder live demo

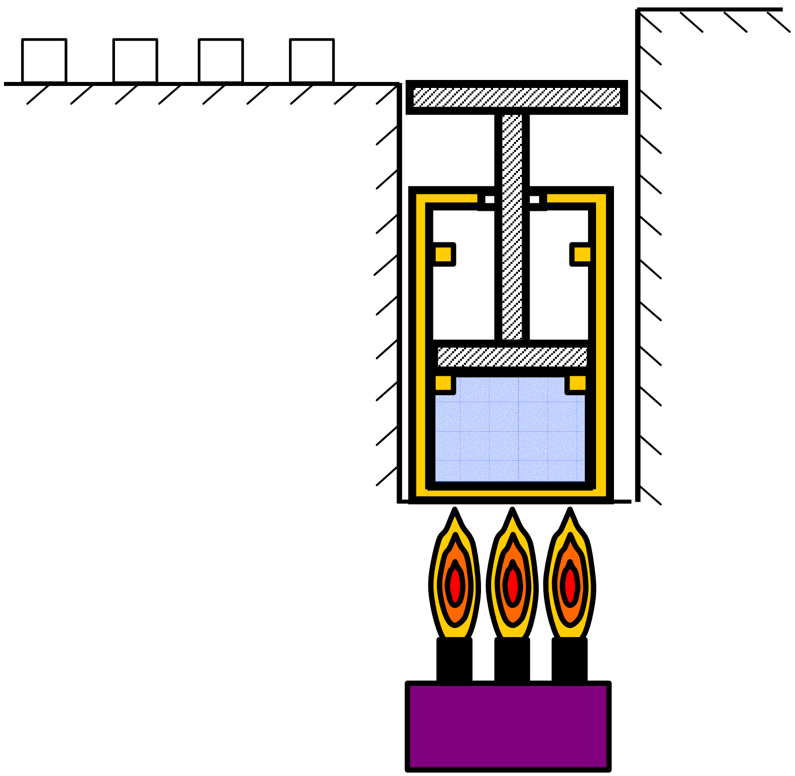
Demonstrate heat transfer as result of work into and work out of a gas

A simple thermodynamic energy converter

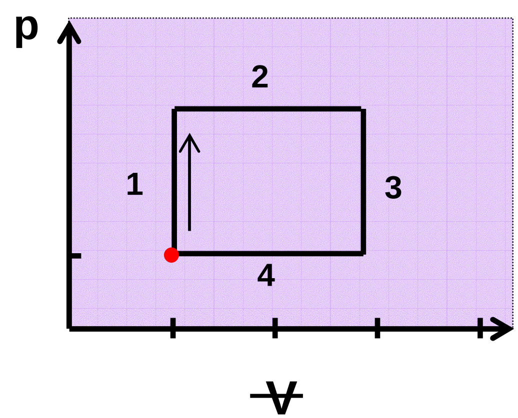
A heat engine operating in a cycle of a piston in a cylinder containing an ideal gas

The engine lifts weights one after the other from a low platform to a high platform

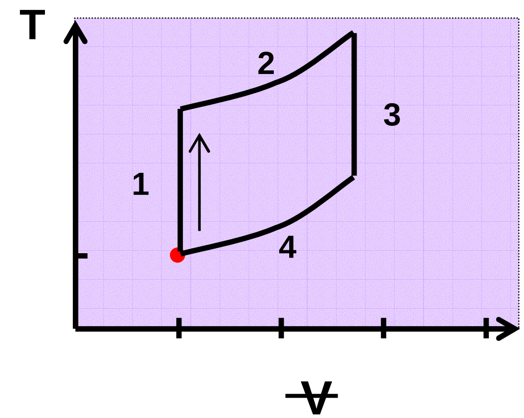
Step 1



Gas pressure



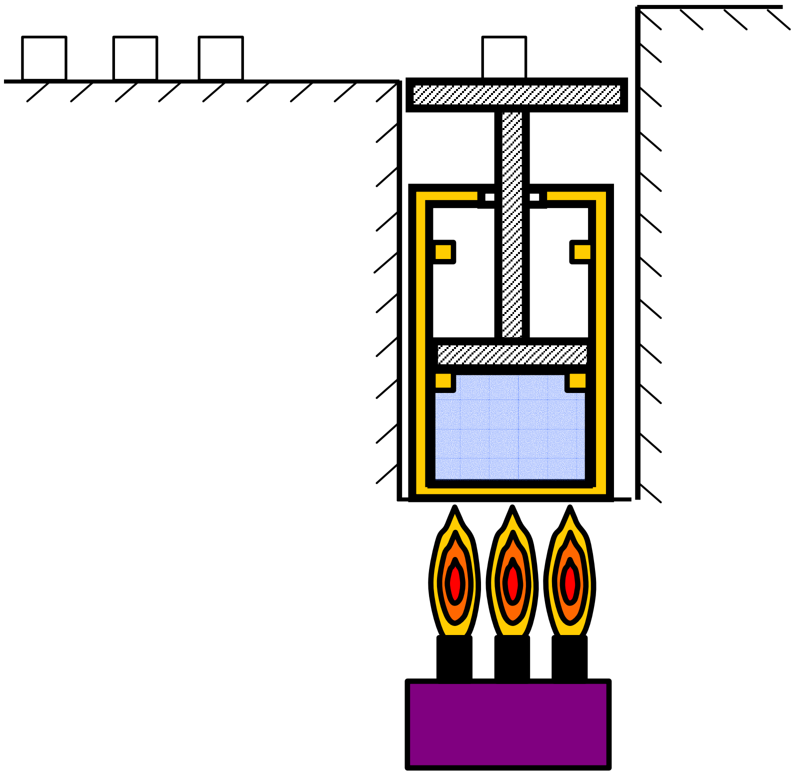
Gas temperature



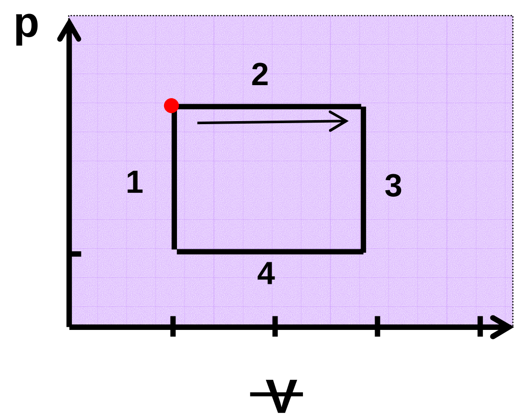
STEP 1:

- Weight to platform
- Heat cylinder
- Pressure increases while piston rests on stops
- Pressure force just supports the weight

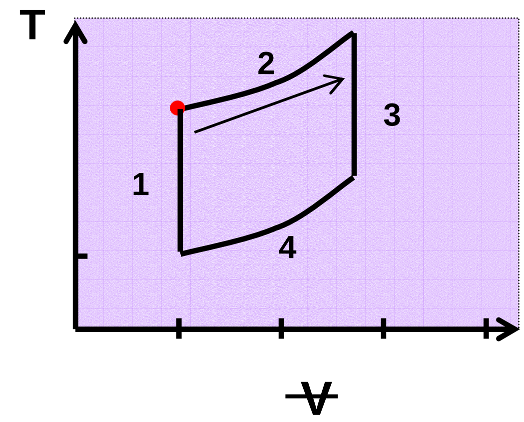
Step 2



Gas pressure



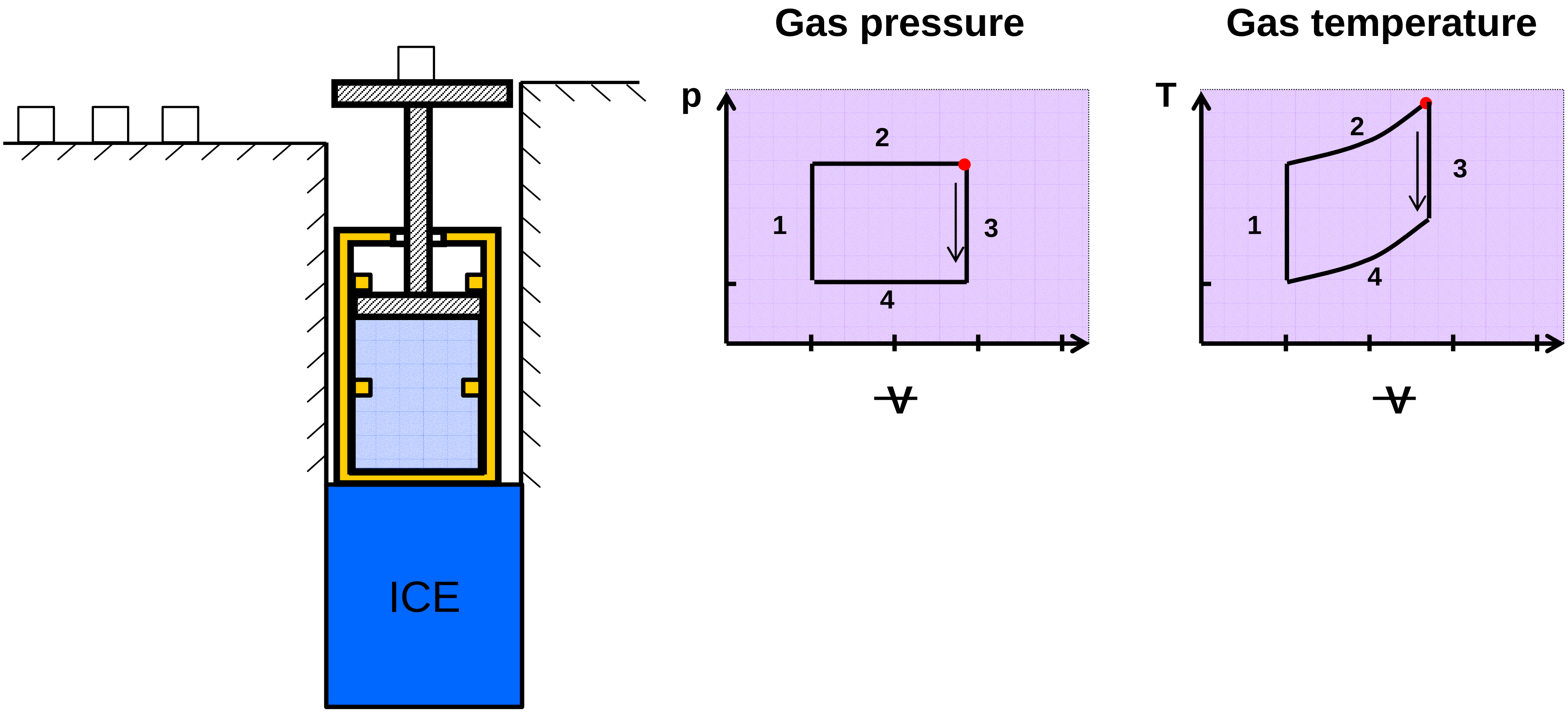
Gas temperature



STEP 2:

- Continue heating
- Gas expands, lifts piston and weight
- Piston assembly rests against top stop

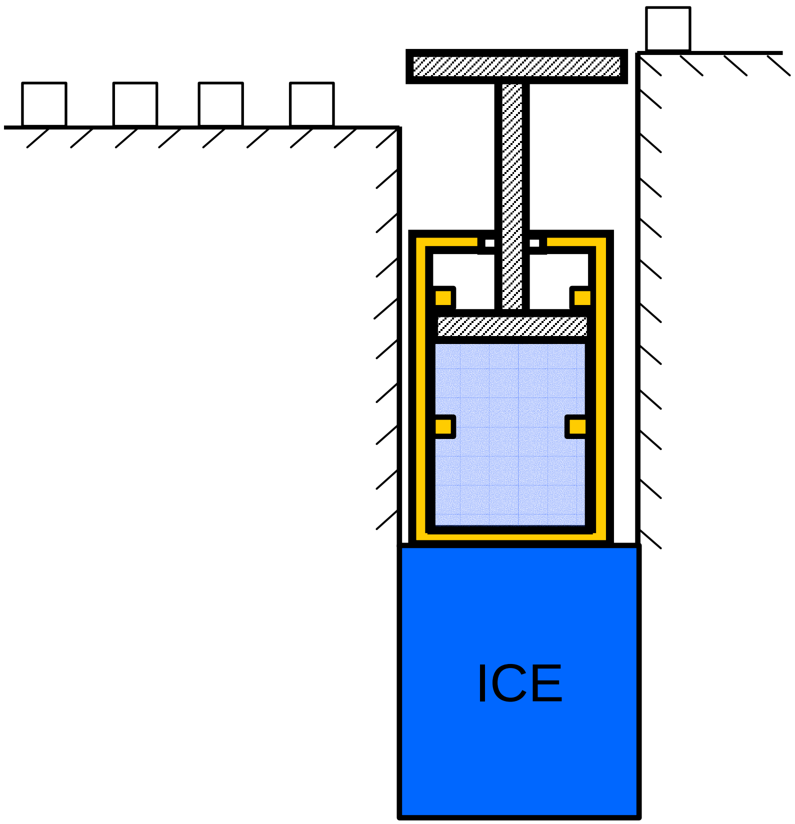
Step 3



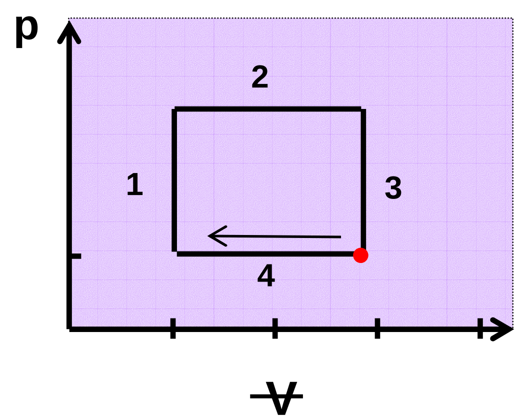
STEP 3:

- Weight off platform
- Pressure decreases while piston is against top stop
- Cool cylinder until gas pressure just supports weight

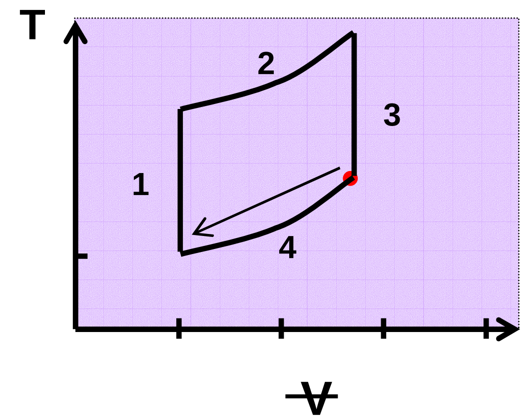
Step 4



Gas pressure



Gas temperature



STEP 4:

- Continue cooling
- Gas contracts, piston lowers
- Piston assembly rests on lower stop

Energy conversion - heat pumping

Heat going from a high temperature to a low temperature can produce work or power. Some of the heat is converted into work.

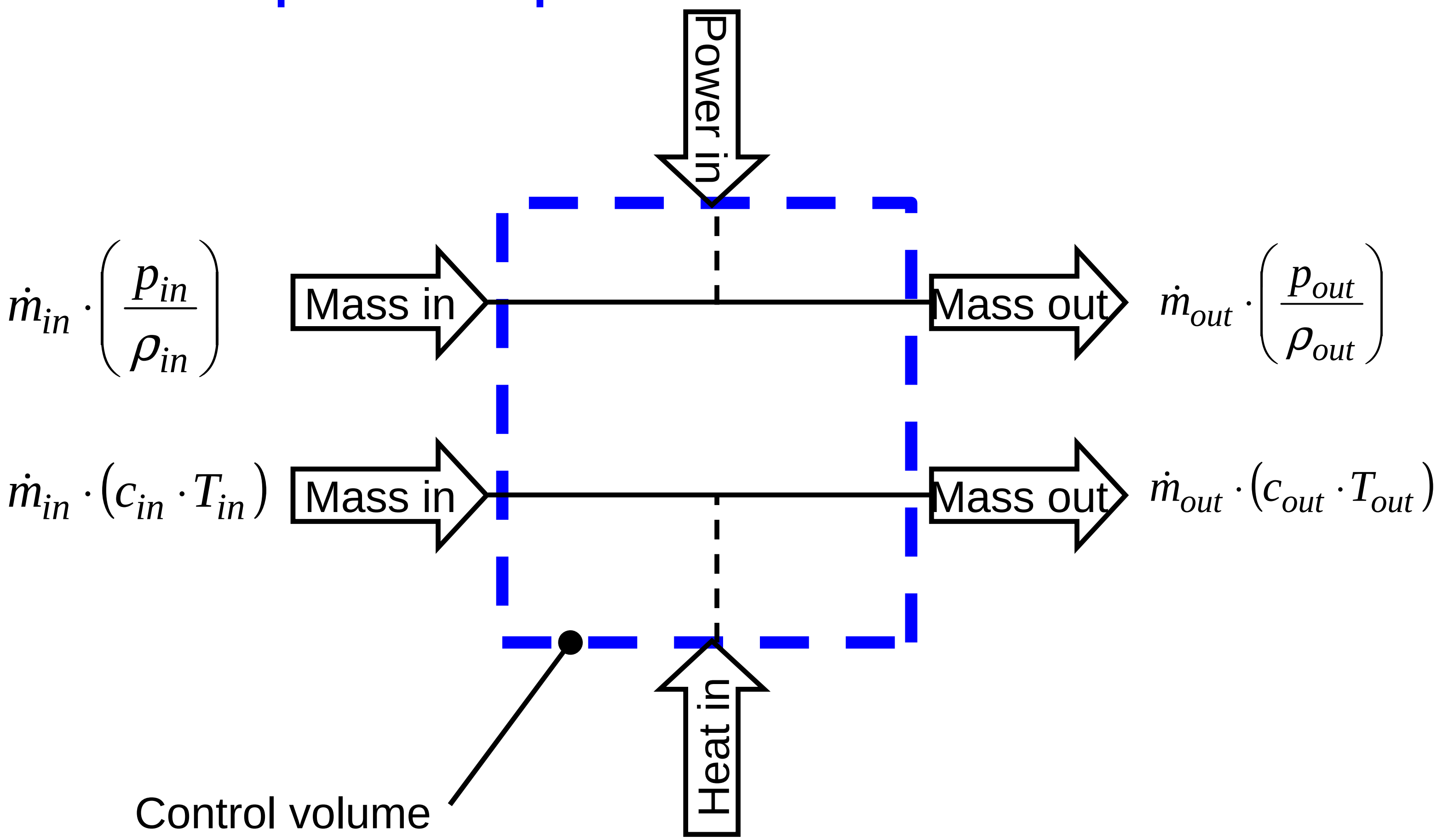
Heat can be made to go from T_{low} to T_{high} by a work input to a cycle of a system with coupled energy storage. This is a heat pump or refrigerator.

Heat transfer from T_{high} to T_{low} without producing work has a loss (of potential work).

This loss is measured by an entropy balance. Entropy is generated by this loss. Entropy generation is a generalization of heat generation in an uncoupled system.

Steady flow energy balance for control volume

Flow of an uncoupled incompressible fluid

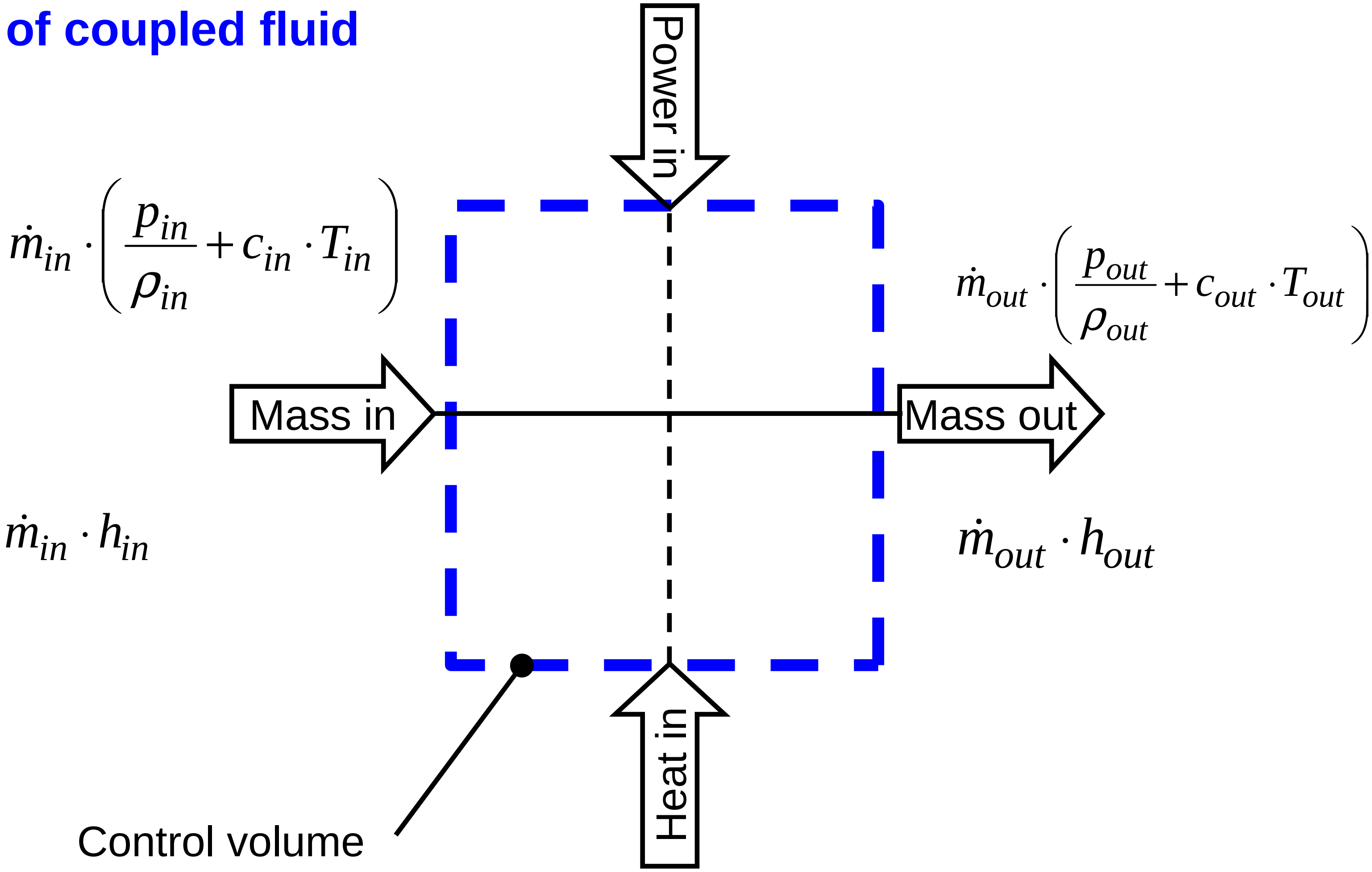


$$Power_{in} = mass_{flow}(1/\rho)[P_{out} - P_{in}]$$

$$Heat_{in} = mass_{flow}c[T_{out} - T_{in}]$$

Steady flow energy balance for control volume

Flow of coupled fluid



$$Power_{in} - Heat_{in} = mass_{flow} \left[\left(\frac{P}{\rho} + cT \right)_{out} - \left(\frac{P}{\rho} + cT \right)_{in} \right]$$

Steady flow energy balance for ideal gas

Definition of enthalpy:

$$h = \frac{P}{\rho} + cT$$

For an ideal gas:

$$\frac{P}{\rho} = Pv = RT$$

$$h = RT + cT = c_p T$$

$$Power_{in} - Heat_{in} = mass_{flow}\left[\left(c_p T\right)_{out} - \left(c_p T\right)_{in}\right]$$

Gas turbine engine

In a steady flow machine without heat transfer or friction to or in the fluid

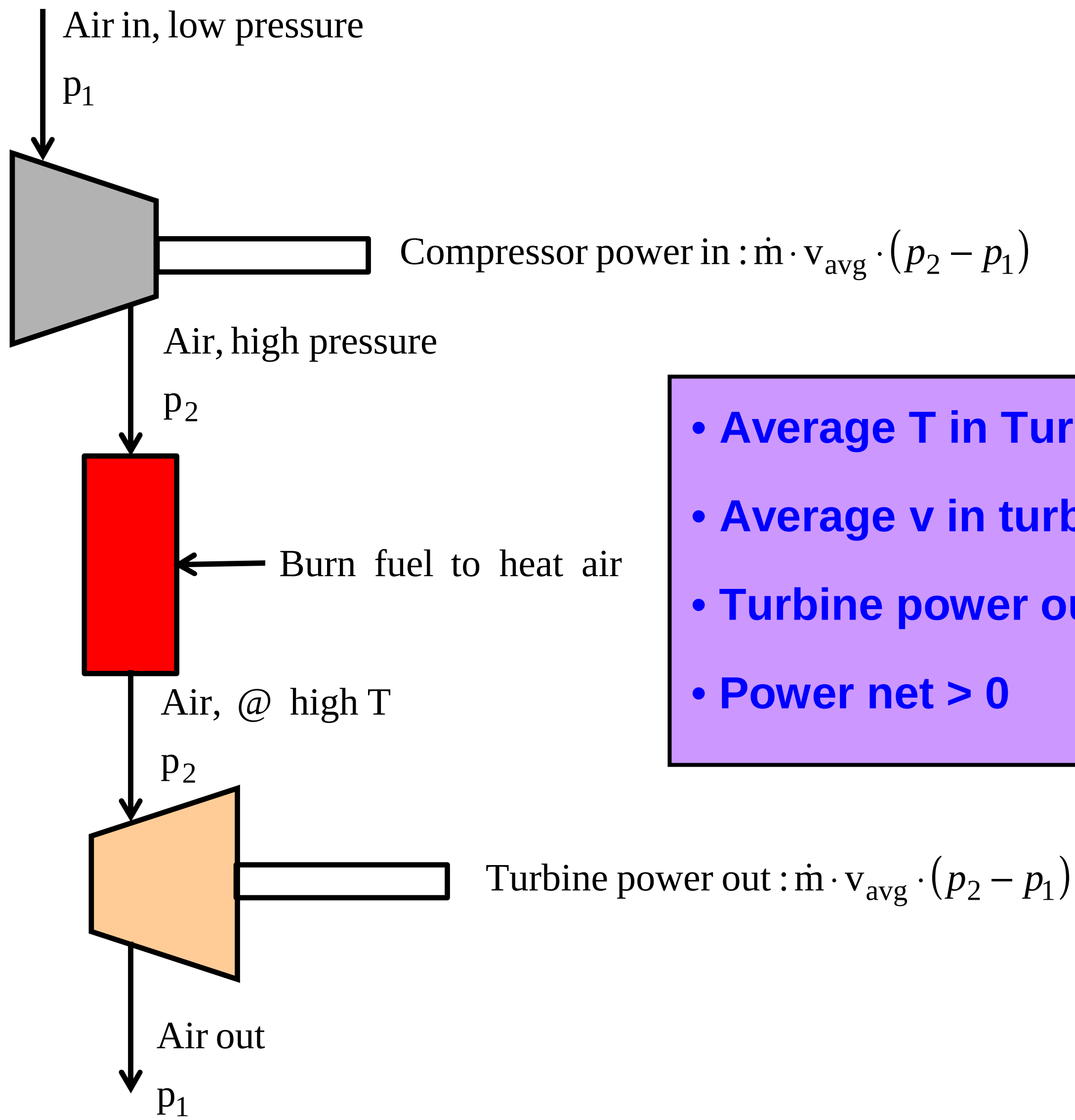
$$power_{in} = mass_{flow} \int_{in}^{out} v\,dP = mass_{flow} v_{avg} \left(P_{out} - P_{in} \right)$$

A gas turbine engine has three basic steady flow components

- **Compressor the increase pressure of stream of air**
- **Burner to heat air by burning fuel**
- **Turbine to decrease pressure of air**

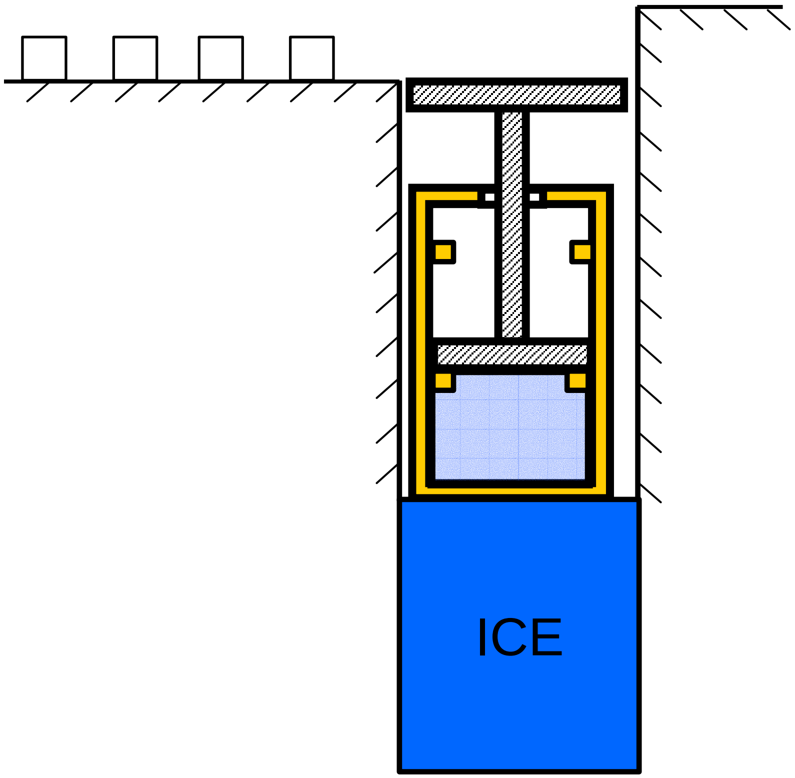
$$Power_{net} = power_{turbine} - power_{comp}$$

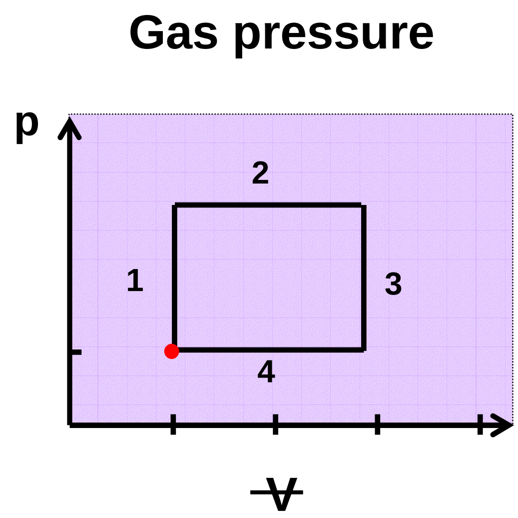
Gas turbine engines

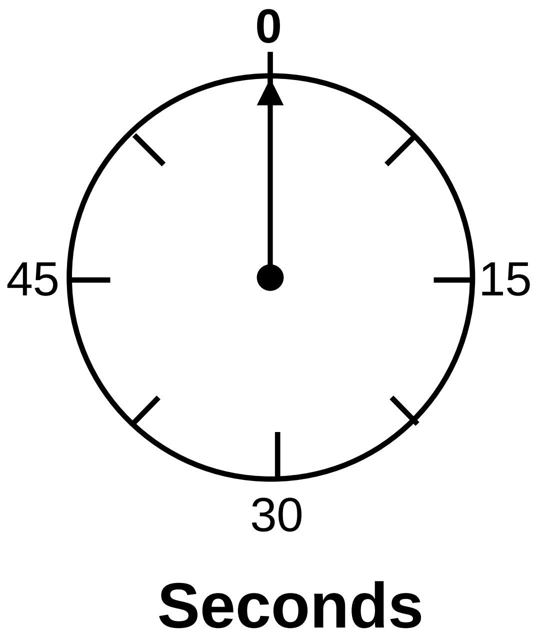


- **Average T in Turbine is greater than in Compressor**
- **Average v in turbine is greater than in compressor**
- **Turbine power out > Compressor power in**
- **Power net > 0**

Group exercise







You have two minutes to determine the work done by this system as a function of pressure and volume