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# EGR3030: Energy Systems and Conversion

## Lecture 1 - Basic principles

Revision on units, use of property tables, and laws of thermodynamics

**Dr Ali Aliyu**
**Senior Lecturer in Sustainable Energy**
AAliyu@lincoln.ac.uk
Office: Room INB3204

# Weekly schedule

| Lecture Fridays 10.30 - 12pm (Room DCB1104); Tutorials 3.00 - 4.30pm (Room MB3201) | | | | |
|---|---|---|---|---|
| **Week** | **Topics** | **Dates, w/c** | | |
| 1 | Basic principles and laws | 23-Sep | | |
| 2 | Gas laws and entropy | 30-Sep | | |
| 3, 4 | Exergy analysis | 07-Oct | & | 14-Oct |
| 5 | Combustion and energy | 21-Oct | | |
| 6 | Gas power cycles | 28-Oct | | |
| 7 | Gas power cycles (morning) and **Guest lecture by Greg Simth, Rolls-Royce (Friday 1.30-3pm)** | 04-Nov | | |
| 8 | *Refrigeration Laboratory practical (INB2202)* | 14-Nov | | |
| 8 | Basic refrigeration, heat pumps, & air conditioning | 11-Nov | | |
| 9 | Basic refrigeration 2 | 18-Nov | | |
| 10 | Energy Systems for Transportation (morning) & Siemens Energy visit (afternoon) | 25-Nov | | |
| 11 | Wind turbines and wind turbine design | 02-Dec | | |
| 11 | Coursework hand-in date | | | |
| 12 | Reading week | 09-Dec | | |
| 13-15 | Christmas break | 16-Dec | to | 30-Dec |
| 16 | Recap | 06-Jan | | |
| 16 | CW2 deadline | | | |
| 17, 18 | Exams | | | |

# Reading list

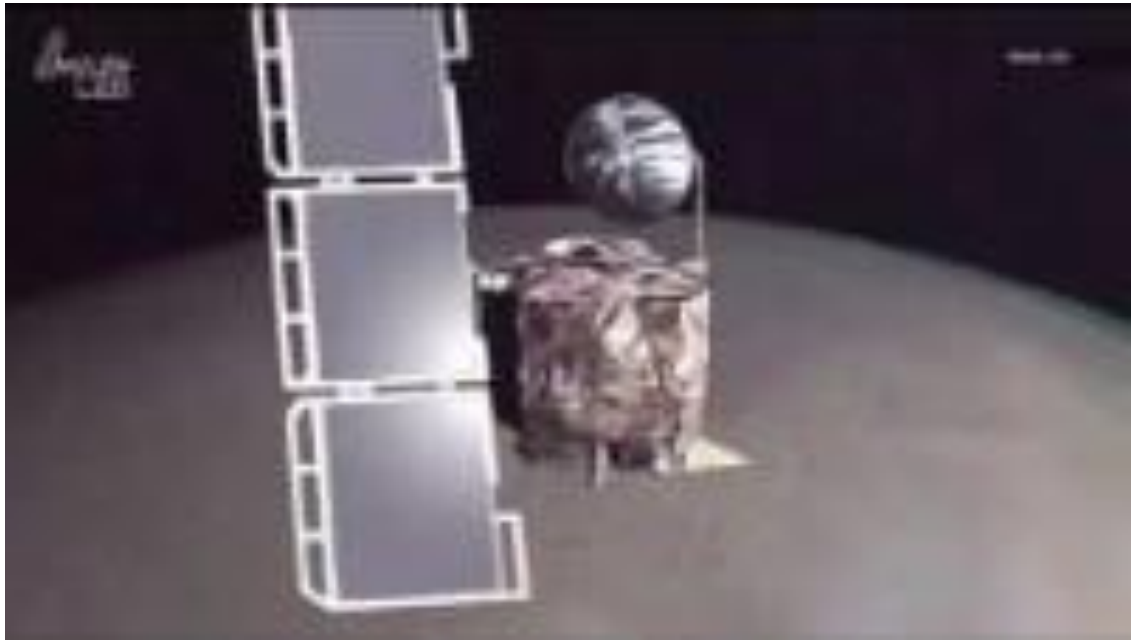
| Title | Item Link | Importance |
|---|---|---|
| **Thermodynamics: an engineering approach** Book, by Yunus A. Cì§engel; Michael A. Boles; Mehmet Kanogl̀u, (2015), Eighth edition in SI units | https://library.lincoln.ac.uk/items/134576 | Essential Reading |
| **Energy systems engineering: evaluation and implementation** Book, by Francis M. Vanek; Louis D. Albright; Largus T. Angenent, (2016) Third edition | https://library.lincoln.ac.uk/items/143149 | Recommended Reading |
| **Fundamentals of thermodynamics** Book, by C. Borgnakke; Richard Edwin Sonntag, 2017, Ninth edition | https://library.lincoln.ac.uk/items/237086 | Recommended Reading |
| **Fundamentals of thermodynamics: SI version** Book, by C. Borgnakke; Richard Edwin Sonntag, (2014), Eighth edition | https://library.lincoln.ac.uk/items/154331 | Recommended Reading |

More in Talis (from the Library): https://rl.talis.com/3/lincoln/lists/66560B53-83CD-0FF0-A3CA-57FA2C04DDF6.html?lang=en-GB&login=1

# Learning outcomes

- Revision on units and scales
- Pressure and temperature scales
- Use of thermodynamic and property tables
- Revision on the laws of thermodynamics

# Nov. 10, 1999: Metric math mistake muffed mass meteorology mission



https://www.youtube.com/watch?v=IWHTyibmB7U

**1999:** A disaster investigation board reports that NASA's Mars Climate Orbiter burned up in the Martian atmosphere because engineers failed to convert units from English to metric.

The $125 million satellite was supposed to be the first weather observer on another world. But as it approached the red planet to slip into a stable orbit Sept. 23, the orbiter vanished.

A NASA review board found that the problem was in the software controlling the orbiter's thrusters. The software calculated the force the thrusters needed to exert in *pounds* of force. A separate piece of software took in the data assuming it was in the metric unit: *newtons*. "The units thing has become the lore, the example in every kid's textbook from that point on," Cook said. "Everyone was amazed we didn't catch it."

https://www.wired.com/2010/11/1110mars-climate-observer-report/

# 21st May, 2014: French railway operator SNCF orders hundreds of new trains that are too big




Video URL: https://www.youtube.com/watch?v=-B_k8W1P2KU

**SNCF's failure to verify measurements results in cost of €50m to narrow 1,300 platforms in one in six regional stations**

France's national railway operator SNCF has ordered 2,000 new trains that were too large for many of the stations they are due to serve.
The train operator has admitted failing to verify measurements it was given by the rail operator before ordering its new rolling stock.
The costly mistake sparked an urgent €50m operation to modify 1,300 platforms on the regional network. In the worst cases SCNF discovered two trains can no longer pass each other on adjacent lines.

The economic newspaper Les Echos said: "It could have been an arithmetic exercise from the old days!"

Story URL: https://www.theguardian.com/world/2014/may/21/french-railway-operator-sncf-orders-trains-too-big

# 5 minute Discussion

- Do you have any examples of such errors to share?

- How can this be avoided?

- Consider Einstein's equation:

$$e = mc^2$$

Are the units true/consistent??

# Know your units, definitions, scales

- Know your units and definitions
  - Basic:- mass= (kg) ; length= metre (m) ; time =Second (s)
  - Force Newton (N) = 1 kg with acceleration of 1m/s
  - Energy Joules (J) = 1 Newton force over 1 metre (Nm)
  - Power Watt (W) = 1 Joule per second (J.s)
  - D.C. Electrical Power (W) = Volts . Amps (V.A)
  - A.C. Electrical Power (W) = Volts . Amps . Power factor (V.A. Cos Ø)

- Scales
  - 1,000 = Kilo
  - 1,000,000= Mega
  - 1,000,000,000 = Giga
  - etc

# Units checking

**<u>ALWAYS</u>** check your units when undertaking a calculation.

**OUR EARLIER EXAMPLE**

Consider Einstein's equation:

$$e = mc^2$$

Are the units true??

Energy = Joules (J) = N.m

N= $\frac{kg.m}{s\,.\,s}$ so J = $\frac{kg.m.\ m}{s\,.\,s}$

$mc^2$ = kg (m/s)^2 = $\frac{kg\ m.m}{s.s}$

i.e. the units are correct

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# The metric prefixes table

| prefix | symbol | factors | decimal number | short scale* (UK/US etc) | long scale* (Europe exc UK) |
|---|---|---|---|---|---|
| **deca** | **da** | **$10^{1}$** | 10 | ten | ten |
| **hecto** | **h** | **$10^{2}$** | 100 | hundred | hundred |
| **kilo** | **k** | **$10^{3}$** | 1,000 | thousand | thousand |
| **mega** | **M** | **$10^{6}$** | 1,000,000 | million | million |
| **giga** | **G** | **$10^{9}$** | 1,000,000,000 | billion | milliard |
| **tera** | **T** | **$10^{12}$** | 1,000,000,000,000 | trillion | billion |
| **peta** | **P** | **$10^{15}$** | 1,000,000,000,000,000 | quadrillion | billiard |
| **exa** | **E** | **$10^{18}$** | 1,000,000,000,000,000,000 | quintillion | trillion |
| **zetta** | **Z** | **$10^{21}$** | 1,000,000,000,000,000,000,000 | sextillion | trilliard |
| **yotta** | **Y** | **$10^{24}$** | 1,000,000,000,000,000,000,000,000 | septillion | quadrillion |
| **deci** | **d** | **$10^{-1}$** | 0.1 | tenth | tenth |
| **centi** | **c** | **$10^{-2}$** | 0.01 | hundredth | hundredth |
| **milli** | **m** | **$10^{-3}$** | 0.001 | thousandth | thousandth |
| **micro** | **µ** | **$10^{-6}$** | 0.000 001 | millionth | millionth |
| **nano** | **n** | **$10^{-9}$** | 0.000 000 001 | billionth | milliardth |
| **pico** | **p** | **$10^{-12}$** | 0.000 000 000 001 | trillionth | billionth |
| **femto** | **f** | **$10^{-15}$** | 0.000 000 000 000 001 | quadrillionth | billiardth |
| **atto** | **a** | **$10^{-18}$** | 0.000 000 000 000 000 001 | quintillionth | trillionth |
| **zepto** | **z** | **$10^{-21}$** | 0.000 000 000 000 000 000 001 | sextillionth | trilliardth |
| **yocto** | **y** | **$10^{-24}$** | 0.000 000 000 000 000 000 000 001 | septillionth | quadrillionth |

# Pressure/temperature scales and conversions

- Gas law calculations are **always** in absolute units.
- **If you do not use absolute units you will get absolute rubbish**
- **Temperature MUST be in °K ( or °R)**
- **Pressure MUST be from zero not gauge**

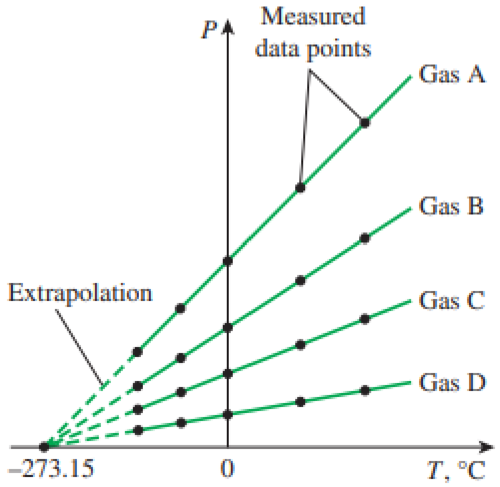
# Temperature scales

- Temperature scales used in the SI and in the English (or imperial) system are:
  - Celsius scale
  - Fahrenheit scale
- On the Celsius scale, ice and steam points were originally assigned the values of 0 and 100°C. On the Fahrenheit scale: 32 and 212°F. These are referred to as two-point scales.
- In engineering, it is desirable to have a temperature scale that is independent of the properties of any substances. Such a scale is called a "thermodynamic temperature scale" (developed based on the 2nd law of thermodynamics)
- The thermodynamic temperature scale in the SI is the Kelvin scale, named after Lord Kelvin (1824–1907). The temperature unit on this scale is the kelvin, designated by K (not °K; the degree symbol was officially dropped from kelvin in 1967).
- Lowest temperature on the Kelvin scale is absolute zero, or 0 K. Then it follows that only one nonzero reference point needs to be assigned to establish the slope of this linear scale.
- The thermodynamic temperature scale in the English system is the Rankine scale, named after William Rankine (1820–1872). The temperature unit on this scale is the rankine, which is designated by R.

$$T(K) = T(°C) + 273.15$$
$$T(R) = T(°F) + 459.67$$

- The temperature scales in the two unit systems are related by

$$T(R) = 1.8T(K)$$
$$T(°F) = 1.8T(°C) + 32$$



# Pressure units

- Pressure is *force per unit area*, it has the unit of newtons per square meter (N/$m^2$), the pascal (Pa). 1 Pa = 1 N/ $m^2$
- A pascal is too small for most pressures encountered in practice. Hence, multiples kilopascal (1 kPa = $10^3$ Pa) and megapascal (1 MPa = $10^6$ Pa) are commonly used.
- Three other pressure units commonly used in practice, especially in Europe, are
  - bar,
  - standard atmosphere,
  - and kilogram-force per square centimetre:

$$1\ bar\ =\ 10\,5\ Pa\ =\ 0.1\ MPa\ =\ 100\ kPa$$

$$1\ atm\ =\ 101{,}325\ Pa\ =\ 101.325\ kPa\ =\ 1.01325\ bars$$

$$1\ \frac{kgf}{cm^2}\ =\ 9.807\ \frac{N}{cm^2}\ =\ 9.807\times 10^4\ \frac{N}{m^2} = 9.807\times 10^4 Pa = 0.9807\ bar\ = 0.9679\ atm$$

- Note that the pressure units bar, atm, and kgf/$cm^2$ are almost equivalent to each other
- In the USA, imperial units are still in use for engineering e.g. psi. $\frac{lbf}{in^2}$. 1 atm = 14.7 psi

# Pressure scales

- The actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum (i.e., absolute zero pressure).
- Most pressure-measuring devices, however, are calibrated to read zero in the atmosphere
- Pressure-measuring devices hence indicate the difference between absolute and the local atmospheric pressure. This difference is called the gauge pressure. $P_{gauge}$ can be positive or negative, but pressures below atmospheric pressure are sometimes called vacuum pressures, measured by vacuum gauges indicating the difference between atmospheric and the absolute pressure. Absolute, gauge, and vacuum pressures are related to each other by

$$P_{abs} = P_{gauge} + P_{atm}$$
$$P_{vac} = P_{atm} - P_{abs}$$

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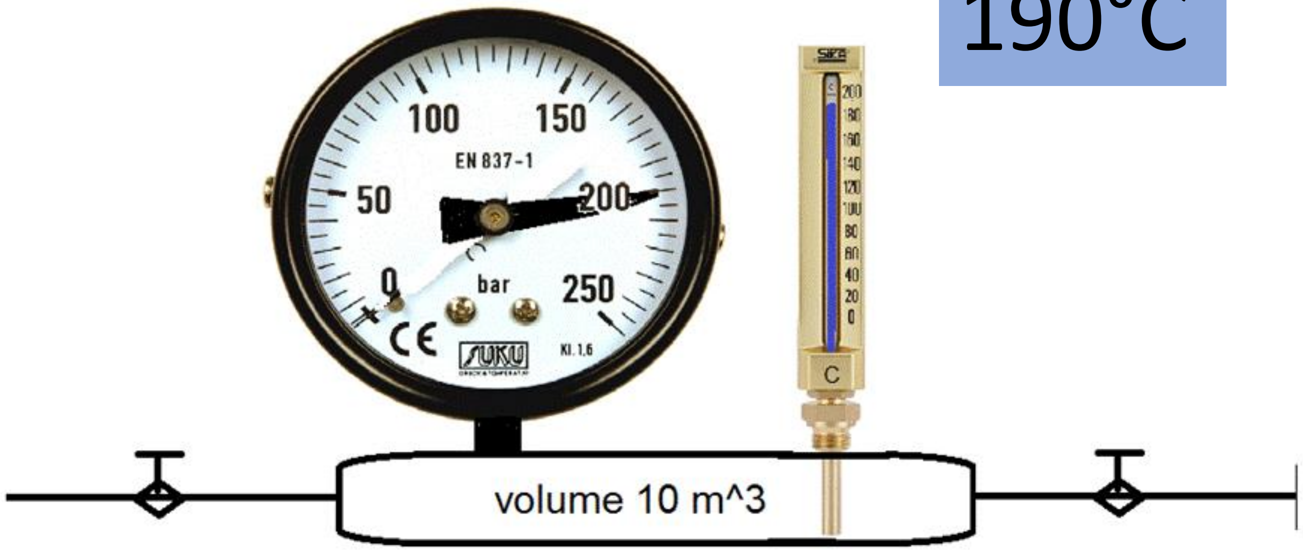
# Pressure readings

- From the gas laws P.V=m.R.T
- Show from units that
- m (mass) = P.V/(R.T)
- Reading Bus store compressed methane as a bus fuel what is the mass in each cylinder?

190°C

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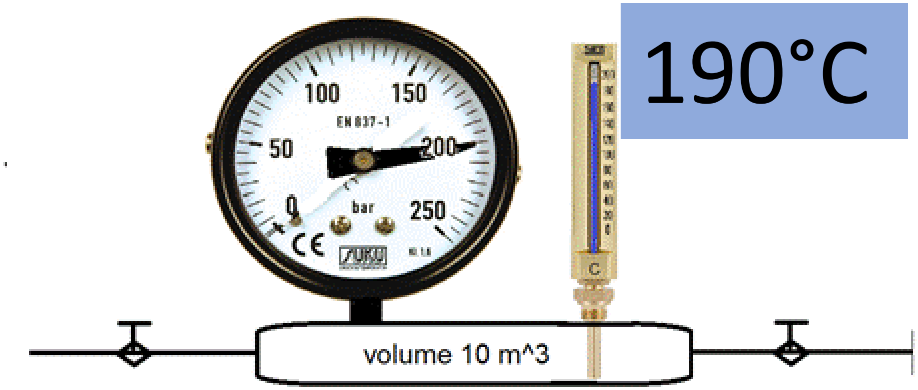
# Common mistakes – pressure conversions




- Pressure is 200 bar + 1.013 for atmosphere as this is GAUGE pressure
- Temperature is 190°C +273.15 to be in °K absolute temperature
- R for Methane $CH_4$ 0.5182 kJ/kg/°K (table A2 thermodynamic tables)

**Needs to be ABSOLUTE**

$$\frac{(200 + 1.013) \times 10^5 \times 10}{0.5182\,(190 + 273.15) \times 10^3}$$

= 837.54 kg

- Without abs conversion, m = 833.318 kg
- Units

$$\frac{N\,.\,m^3\,.\,kg\,.\,K}{m^2\,.\,kJ\,.\,K}$$

$$\frac{N\,.\,m^3\,.\,kg\,.\,K}{m^2\quad KN.\,m.\,K}$$

# Appendix 1

## PROPERTY TABLES AND CHARTS (SI UNITS)





**Table A–2** Ideal-gas specific heats of various common gases



**TABLE A–2**

Ideal-gas specific heats of various common gases

(a) At 300 K

| Gas | Formula | Gas constant, $R$ kJ/kg · K | $c_p$ kJ/kg · K | $c_v$ kJ/kg · K | $k$ |
|---|---|---|---|---|---|
| Air | — | 0.2870 | 1.005 | 0.718 | 1.400 |
| Argon | Ar | 0.2081 | 0.5203 | 0.3122 | 1.667 |
| Butane | $C_4H_{10}$ | 0.1433 | 1.7164 | 1.5734 | 1.091 |
| Carbon dioxide | $CO_2$ | 0.1889 | 0.846 | 0.657 | 1.289 |
| Carbon monoxide | CO | 0.2968 | 1.040 | 0.744 | 1.400 |
| Ethane | $C_2H_6$ | 0.2765 | 1.7662 | 1.4897 | 1.186 |
| Ethylene | $C_2H_4$ | 0.2964 | 1.5482 | 1.2518 | 1.237 |
| Helium | He | 2.0769 | 5.1926 | 3.1156 | 1.667 |
| Hydrogen | $H_2$ | 4.1240 | 14.307 | 10.183 | 1.405 |
| Methane | $CH_4$ | 0.5182 | 2.2537 | 1.7354 | 1.299 |
| Neon | Ne | 0.4119 | 1.0299 | 0.6179 | 1.667 |

| | | |
|---|---|---|
| Methane | $CH_4$ | 0.5182 |

# Thermodynamic Tables

## You need to know how to use these

Appendix 1

PROPERTY TABLES AND CHARTS (SI UNITS)





We will be using the tables in the appendices of the book:
Cengel & Boles, Thermodynamics: An Engineering Approach, SI Unit Editions

# Remember your laws of thermodynamics

- The first law of thermodynamics is a version of the law of conservation of energy, adapted for thermodynamic processes. It distinguishes energy transfer into three kinds as:
  - heat,
  - thermodynamic work, and
  - energy associated with matter transfer,

  relating them to a function of a body's state, called internal energy

$$\Delta U = Q - W$$

$\Delta U$ denotes the change in the internal energy of a closed system.

- The second law of thermodynamics indicates the irreversibility of natural processes. It implies the existence of a quantity called the entropy S of a thermodynamic system. In entropy terms:

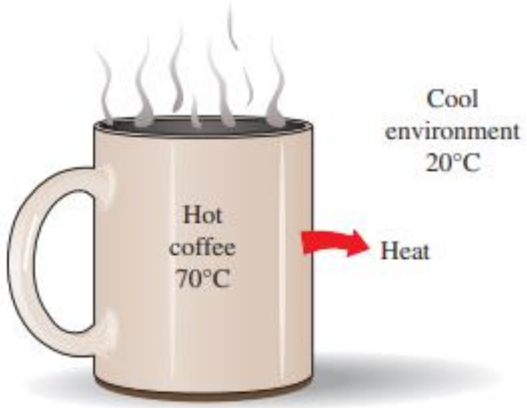
$$\delta Q = T\, dS$$

Reversible processes are a useful and convenient theoretical limiting case, all natural processes are irreversible.

- The third law of thermodynamics can be stated as:

A system's entropy approaches a constant value as its temperature approaches absolute zero (0 K).

At 0 K, the system must be in the state with the minimum thermal energy, the ground state.




A cup of hot coffee left on a table eventually cools, but a cup of cool coffee in the same room never gets hot by itself

# Use of (engineering) software

We will solve some problems in this module using:

- Excel
- Matlab

To give you competence using them to do your calculations e.g., in:

- Solving equations such as the gas laws
- Fitting experimental data to “models”
- Plotting and visualising data

# Problem solving technique

- Step 1: problem statement
- Step 2: draw a schematic – and annotate it with known info/variables
- Step 3: make assumptions and approximations
- Step 4: apply physical laws
- Step 5: determine unknown properties at known states to solve the problem from relationships or tables
- Step 6: substitute known quantities and perform calculations
- Step 7: reasoning, verification and discussion – check to make sure that the results are reasonable, intuitive and verify the validity of assumptions

# Worked example

Humans are most comfortable when the temperature is between 65°F and 75°F.

a. Express these temperature limits in °C.
b. Convert the size of this temperature range (10°F) to K, °C, and R.
c. Is there any difference in the size of this range as measured in relative or absolute units?

Answers:

- $18.3°\ C\ \ - 23.9°\ C$
- $10\ R$
- $5.6°\ C\ and\ K$

# Questions to think about

Practice checking of units and factors for calculations and use of themodynamic tables

1. What are the units of:- $\frac{Pressure}{R\,\{gas\ const\}.Temperature}$?
2. Speed of sound in a gas is given by $\sqrt{\gamma\ R\ T}$ what are the units? γ = ratio of specific heats   R = gas constant   T = Temperature
3. Show rotational speed x Torque = power
4. What are the units of m. Cp(ΔT). With m=mass   Cp = specifc heat at const pressure   ΔT= differential temperature
5. Are the units of Ut the same as ½ $ft^2$? U = initial velocity   f = acceleration   t = time
6. Can the universal gas const R be calculated from $P/(T\,.\,\rho)$? P= Pressure   T = Temperature   ρ = density
7. A tractor is pulling a plough at 2 m/s with a drag force of 500N what are the units and result?
8. **What is the gas const R for air and its units**
9. **Which has the highest heat capacity at constant pressure air or steam @ 300K?**
10. **What is γ for air at 1000K?**
11. **From table A2 p913 calculate Cp for Acetylene $C_2H_2$ at 1000K**
12. **What is the lowest temperature a mercury in glass thermometer can read?**
13. **Can you float molten glass on liquid lead?**
14. **Which freezes first apples or tomatoes?**
15. **At what temperature would the dead sea freeze (20% sodium chlorate in water)?**
16. **How much energy is needed to convert 1kg of water into steam @ a pressure of 1.013bar?**
17. **This is given as $h_{fg}$ What is the specific density of liquid water [$m^3$/kg] at 10,000 kPa? (& what is kPa ?)**
18. **Do you need extra oxygen and heating at 10,000 metres altitude?(temp & pressure)**
19. How much higher could you jump as a % from sea level?
20. What is the lower and higher heating vales of gasoline fuel?
21. It takes 3 min to fill a 50litre tank with diesel on my car what is the energy transfer rate in kJ/s
22. What would be the equivalent current (amps) for this energy transfer rate if this were to charge a 12Volt battery for an electric vehicle?

# Recap

We discussed:

- Revision on units and scales
- Pressure and temperature scales
- Use of thermodynamic and property tables
- Revision on the laws of thermodynamics