4T Modelling Thermodynamics and Equilibrium of mixture of radiation field, ionic gas and electron gas

Constants and Functions

electron-ion collision cross sections
typically 10^(-11) m^2
https://www.nist.gov/system/files/documents/srd/jpcrd386.pdf

```
(* Initial parameters and constants *)

c = 3.0 * 10^(8)
ep0 = 8.8541878128 * 10^(-12);
kb = 1.380649 * 10^(-23);
ee = 1.602 * 10^(-19);
na = 6.02 * 10^23; (* avogadros number*)

a = 2 * 10^(-10);
mp = 1.67262192 * 10^(-27);
md = 2.014102 * mp;(*mass deuterium*)
mt = 3.016049 * mp;(*mass tritium*)
mal = 4.002603 * mp; (**)
hbar = 1.05457182 * 10^(-34);
me = 9.1093837 * 10^(-31);
mme = me * na; (* molar electron mass*)
ui = 13.6 * ee;(* ionization energy for hydrogen*)

ar = 5.670374 * 10^(-8) ;(* stefan-boltzmann constant *)

sigmaie = 1.0 * 10^(-11); (* e- ion collision cross section  m^2*)
sigmaii  = Pi * a * a; (* ion ion collision cross section based on atomic size *)

(*Nuclear Constants for burning and transfer*)
sigt = (8 / Pi) * (ee^2 / (me * c * c))^2; (*thompson cross section*)
```

Out[72]=

$3. \times 10^{8}$

Model Parameters

```
(*The model parameters*)
Ni = 1; (* number of moles of ions in total*)
ni0 = 1.0; (*initial number of moles of ions*)
ne = Ni; (* number of electrons*)
```

In[84]:=
```
(* Saha equation*) (* Here calculate the ionization fraction *)
x[N_, T_, Ne_] :=
  ((2 * Pi * me * kb / hbar) ^ (3 / 2)) * (T^ (3 / 2) / Ne) * Exp[- (ui / (kb * T))];
(* Ne is electron number density *) (* typical ne 10^(-20) *)

(* time between collisions ... relaxation time*)
taun[N_, T_] := (1 / (N * sigmaii)) * Sqrt[mp / (kb * T)];
taue[Ne_, Te_] := (1 / (Ne * sigmaie)) * Sqrt[me / (kb * Te)]
```

In[ ]:=

Radiation and Perfect Gas

Out[ ]=

and Gas Perfect Radiation

In[87]:=
```
pr[N_, Vo_, T_] := (N * kb * T / Vo) + (ar * T^4) / 3;
Et[N_, Vo_, T_] := (3 / 2) * (N * kb * T) + (Vo * ar * T^4);
St[N_, Vo_, T_] := N * kb * Log[Vo * T^ (3 / 2)] + (4 / 3) * ar * Vo * T^3
```

Radiation and Ionic Gas

```
(*   using saha equation  to get energy
 and pressure for ionic gas and radiation field*)
```

Planck and Bose Einstein Distribution

```
(*  Planck distribution*)
```

In[90]:=
```
npl[nu_, T_] := 1.0 / (Exp[2 * Pi * hbar * nu / (kb * T)] - 1.0)
```

```
(* Bose-Einstein distribution*)
```

In[91]:=
```
nbe[nu_, mu_, T_] := 1.0 / (Exp[((2 * Pi * hbar * nu) / (kb * T)) - mu] - 1.0)
```

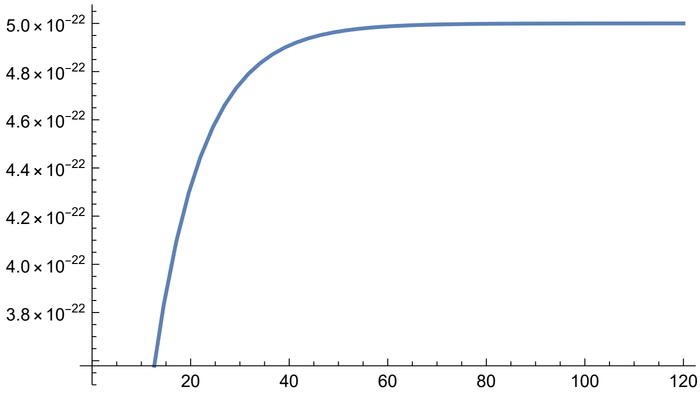
In[92]:=
```
fbe[ep_, al_] := 1.0 / (Exp[ep + al] - 1.0);
```

Rates for Nuclear Reactions

```
(* rates for nuclear reactions*)
```

In[135]:=
```
Adt = 5.0 * 10^(-22); (* m^3/s*)
kdt = 0.1;
T0dt = 1.0;
sigvdt[T_] := Adt * (T0dt - Exp[-kdt * T]);
(*DT fusion reaction cross section sigv*) (*T is the temperature in keV*)
Plot[sigvdt[x1], {x1, 0, 120}]
```

Out[139]=




```
(* functions *)
nuc[ne_] := c * sigt * ne(* compton strength*);
lambda[te_, ne_] := 25.127 - Log[(ne^0.5) / (1000.0 * te)];
fali[te_] := te / (te + 32);

(*mme molar mass of electron*)
pei[ne_, ni_, nal_, te_, ti_] :=
  (6 / Sqrt[Pi]) * nuc[ne] * ni * ((mme / md) + (mme / mt) + 4 * ((ni0 - ni) / ni) * (mme / mal)) *
   ((me * c * c / (2 * te)) ^ (3 / 2)) * Log[lambda[te, ne]] * (ti - te);
```

Experiments

In[93]:=
```
2 * Pi * hbar / kb
```

Out[93]=

4.79924×10^{-11}

In[94]:=
```
nur = 3.0 * 10^(17)
myl = {nbe[nur, 0.005, T], nbe[nur, 0.1, T] , nbe[nur, 0.2, T] , nbe[nur, 0.3, T]}
Plot[myl, {T, 10 * 10^6, 500 * 10^6}]
```

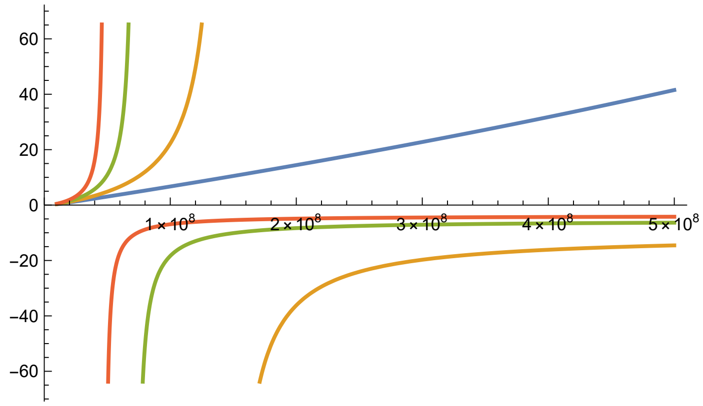
Out[94]=

$3. \times 10^{17}$

Out[95]=

$$\left\{\frac{1.}{-1. + e^{-0.005+\frac{1.43977\times10^{7}}{T}}}, \frac{1.}{-1. + e^{-0.1+\frac{1.43977\times10^{7}}{T}}}, \frac{1.}{-1. + e^{-0.2+\frac{1.43977\times10^{7}}{T}}}, \frac{1.}{-1. + e^{-0.3+\frac{1.43977\times10^{7}}{T}}}\right\}$$

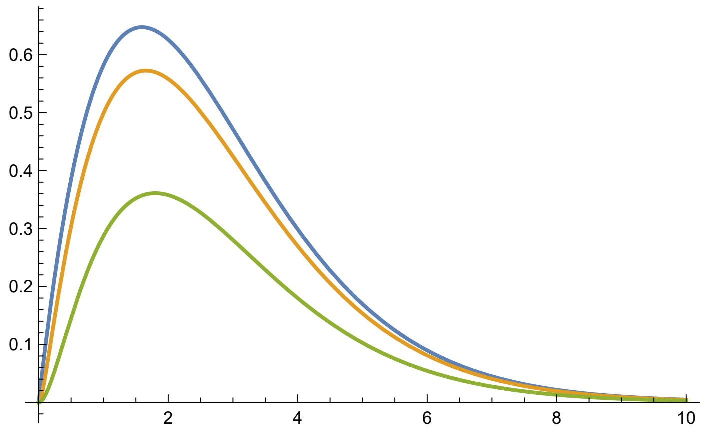
Out[96]=



In[104]:=

```
Plot[{x1^2 * fbe[x1, 0], x1^2 * fbe[x1, 0.1], x1^2 * fbe[x1, 0.5]}, {x1, 0, 10}]
```

Out[104]=



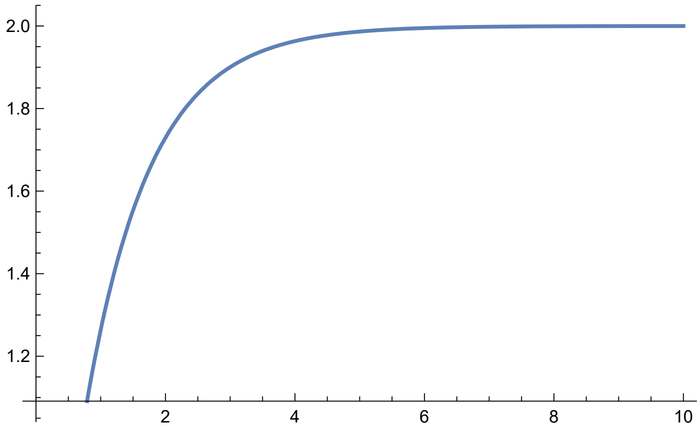
In[105]:=

```
A = 2;
k = 1;
x0 = 1.0;
```

In[108]:=

```
y1[x_] := A * (x0 - Exp[-k * x]);
Plot[y1[x1], {x1, 0, 10}]
```

Out[109]=



Out[38]=