- -

Выделим условно четыре периода развития взрыва: период испарения и ионизации вещества –
, , ,
, ,
.

,

$$\frac{dN}{dv_0} = N\left[\frac{m}{2\pi kT}\right]^{3/2} v^2 \exp\left(-\frac{mv^2}{2kT}\right) \qquad (2.13)$$

clear :

Значение постоянной	Размерность
$1{,}380\,6504(24)\times10^{-23}$	Дж·К$^{-1}$
$8{,}617\,343(15)\times10^{-5}$	эВ·К$^{-1}$
$1{,}3807\times10^{-16}$	эрг·К$^{-1}$

$k := 1.3806504\cdot10^{-23}$:

=
9.10938356 × 10-31 килограмма

$m_e := 9.10938356\cdot10^{-31}$:

=
1.60217662 × 10-19 Кулона

$q_e := 1.60217662\cdot10^{-19}$:

$c := 299792458$

299792458 **(1)**

$\mu_0 := 4\cdot\pi\cdot 10^{-7}$

$$\frac{1}{2500000}\,\pi \tag{2}$$

$\varepsilon_0 := \dfrac{1}{\mu_0\cdot c^2}$

$$\frac{625000}{22468879468420441\,\pi} \tag{3}$$

= 6 4 / / 6 . 0 2 2 1 4 * 1 0 2 3

$N_A := 6.02214\cdot 10^{23}$

$$6.022140000\;10^{23} \tag{4}$$

$m_{Cu} := \dfrac{64\cdot 10^{-3}}{N_A}$

$$1.062745137\;10^{-25} \tag{5}$$

« 0 . 2 , , ,
1 0 » « 3 0 0 5 0 .
~ 5 0 0 . , 3 0 0
5 0 1 6 2 ,

$E1_c := evalf\left(\dfrac{6000\cdot 10^{-6}\cdot 300^2}{2} - \dfrac{6000\cdot 10^{-6}\cdot 50^2}{2}\right)$

$$262.5000000 \tag{6}$$

~ 2 7 0 .
, ,
~ 1 0 , ~ 1 5 0
. »

.
,
. ,
, . . . ,
1 г , 2 г .
(3 . 3 4) ,

0 . 1 1 , 0 . 1 5 .

, ,
. ,
. 7 3 0 .
, ,
3.4x10-14 .

$$dq_{experiment} := \frac{4\cdot\pi\cdot\varepsilon_{0}\cdot(-30\cdot10^{-3})}{\left(\frac{1}{0.11^{2}}-\frac{1}{0.15^{2}}\right)}$$

$$-8.738047433\ 10^{-14} \qquad (7)$$

, ,
0 . 2 5 8 .
2 8 0 0 .
3 0 0 0 , 3 0 0 1 3 4 .

$$E_{c} := \frac{3000\cdot10^{-6}\cdot300^{2}}{2}$$

$$135 \qquad (8)$$

, 1 2 5
, ,
.

$$V_{Cu\_sgs} := \pi\cdot0.01^{2}\cdot0.5$$

$$0.0001570796327 \qquad (9)$$

^ 3

$$M_{Cu\_sgs} := 8.92\cdot V_{Cu\_sgs}$$

$$0.001401150324 \qquad (10)$$

$$M_{molar\_sgs} := 63.546$$

$$63.546 \qquad (11)$$

$$\nu_{Cu} := \frac{M_{Cu\_sgs}}{M_{molar\_sgs}}$$

$$0.00002204938665 \qquad (12)$$

$$N_{i} := \nu_{Cu}\cdot N_{A}$$

$$1.327844933\ 10^{19} \qquad (13)$$

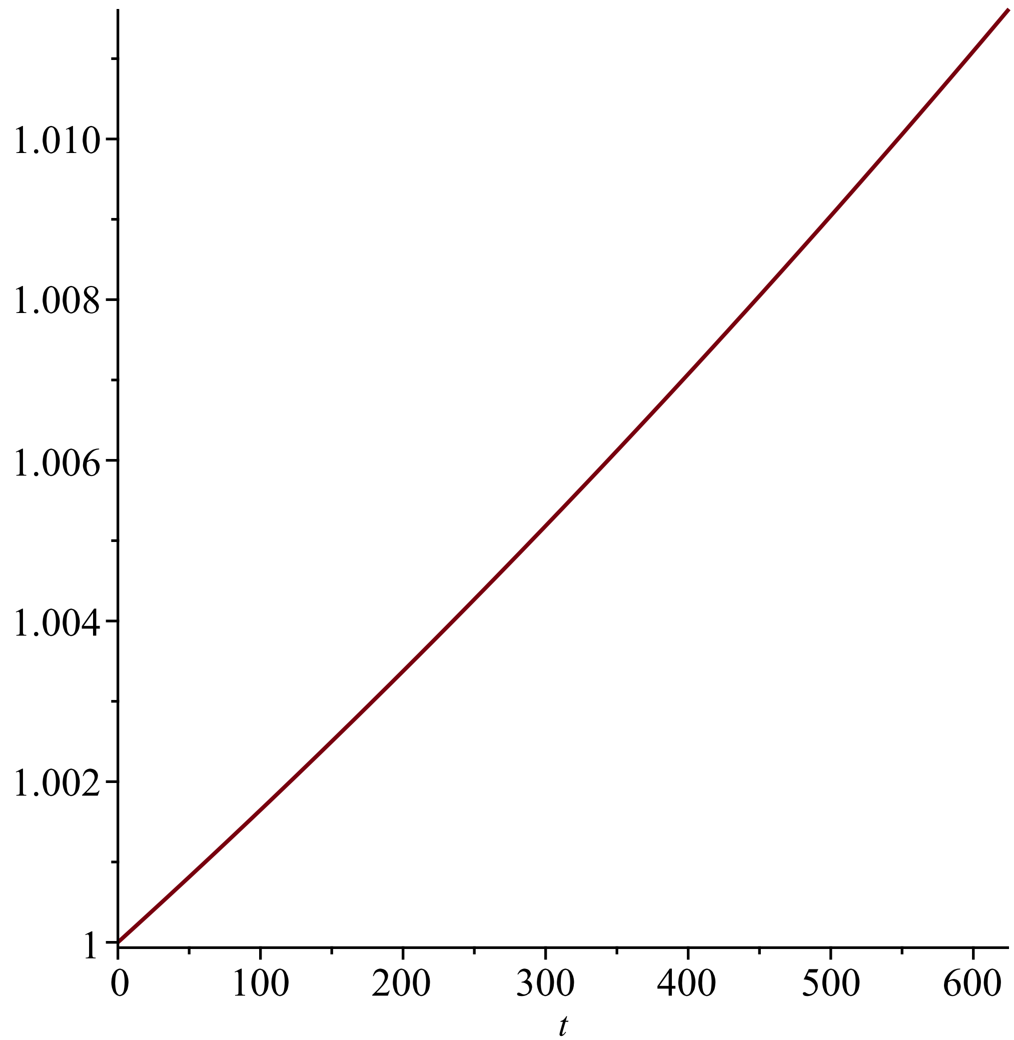
$$N_{A}\cdot k$$

$$8.314470000 \qquad (14)$$

$a(t) := \left(1 + 1.607 \cdot 10^{-5} \cdot t + 0.403 \cdot 10^{-8} \cdot t^2\right)$

$$t \rightarrow 1 + \frac{1.607\, t}{100000} + \frac{0.403\, t^2}{100000000} \tag{15}$$

$with(plots) : plot(a(t), t = 0 ..625)$



$a(2567)$

$$1.067807331 \tag{16}$$

http://thermalinfo.ru/svojstva-materialov/metally-i-splavy/svojstva-medi-plotnost-teploemkost-teploprovodnost

T, К	d, г/см³	c_p, Дж/(кг·К)	$a\cdot10^6$, м²/с	λ, Вт/(м·К)		$\rho\cdot10^8$, Ом·м	$\frac{L}{L_0}=\frac{\lambda}{\lambda_e^L}$	$\frac{C_P}{C_V}$
50	—	—	—	1250	—	0,0518	—	1,001
100	—	—	—	482	—	0,348	—	1,005
200	—	—	130	413	—	1,048	—	1,01
300	8,933	385,0	117	401,9	401	1,725	0,945	1,02
400	8,870	397,7	111	391,5	393	2,402	0,961	1,04
500	8,628	408,0	107	385,4	386	3,090	0,976	1,05
600	8,779	416,9	103	376,9	379	3,792	0,976	1,06
700	8,728	425,1	99,7	369,7	373	4,514	0,976	1,08
800	8,656	432,9	96,3	360,8	366	5,262	0,973	1,09
900	8,622	441,7	93,3	355,3	359	6,041	0,979	1,11
1000	8,567	451,4	90,3	349,2	352	6,858	0,979	1,13
1100	8,509	464,3	85,5	337,6	346	7,717	0,972	1,15
1200	8,451	480,8	80,6	327,5	339	8,626	0,970	1,18
1300	8,394	506,5	75,8	322,1	332	9,592	0,972	1,20
1357,6$_s$	8,361*	525,2*	72,3*	317*	—	10,171	0,972*	—
1357,6$_l$	8,00*	513,9*	41,2*	175*	—	21,01	1,08*	—
1400	7,98	513,9	42,7	175	—	21,43	1,08	—
1600	7,96	513,9	15,2	184	—	23,42	1,1	—

* Данные нуждаются в уточнении.

tab1_T ≔ [300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1357.6] :

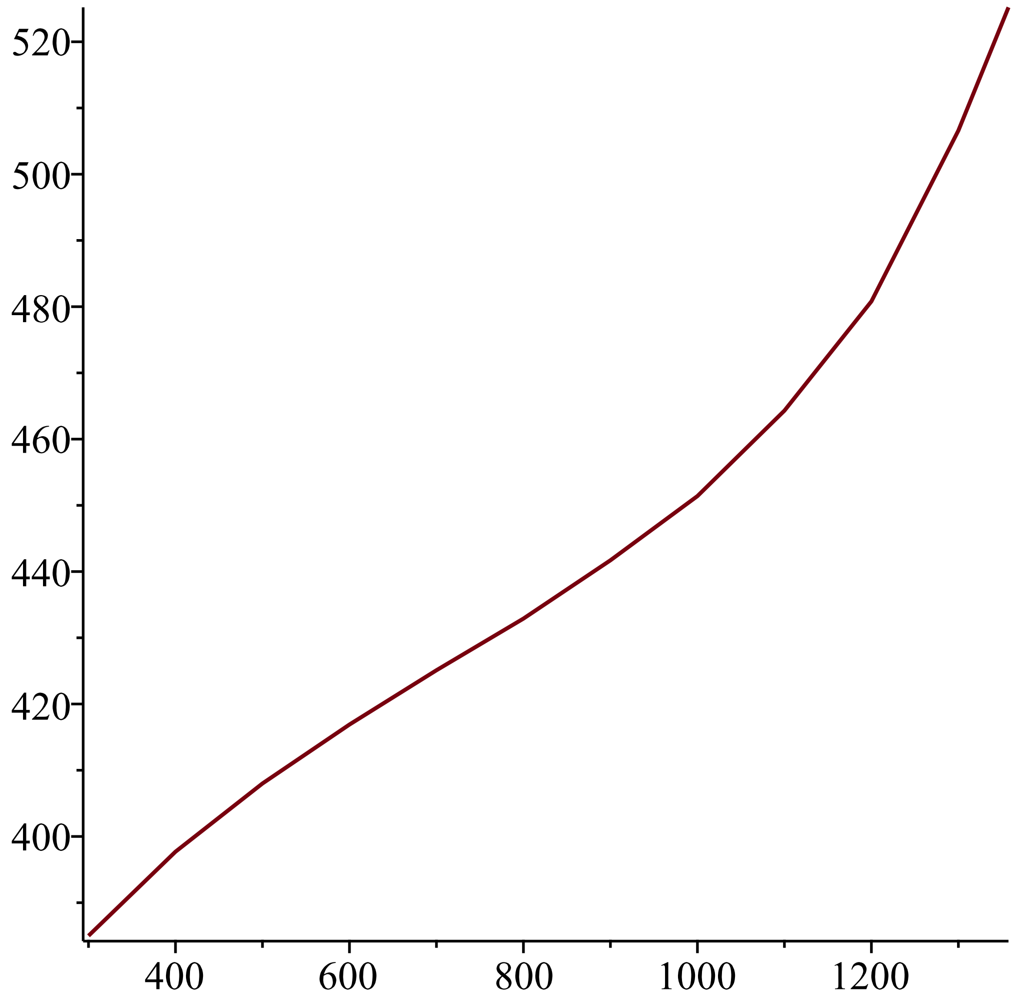
tab1_Cp ≔ [385.0, 397.7, 408.0, 416.9, 425.1, 432.9, 441.7, 451.4, 464.3, 480.8, 506.6, 525.2] :

/ (*)

$tab1\_Cp \cdot M_{molar\_sgs} \cdot 0.001$

[24.4652100, 25.2722442, 25.9267680, 26.4923274, 27.0134046, 27.5090634, 28.0682682, 28.6846644, 29.5044078, 30.5529168, 32.1924036, 33.3743592] **(17)**

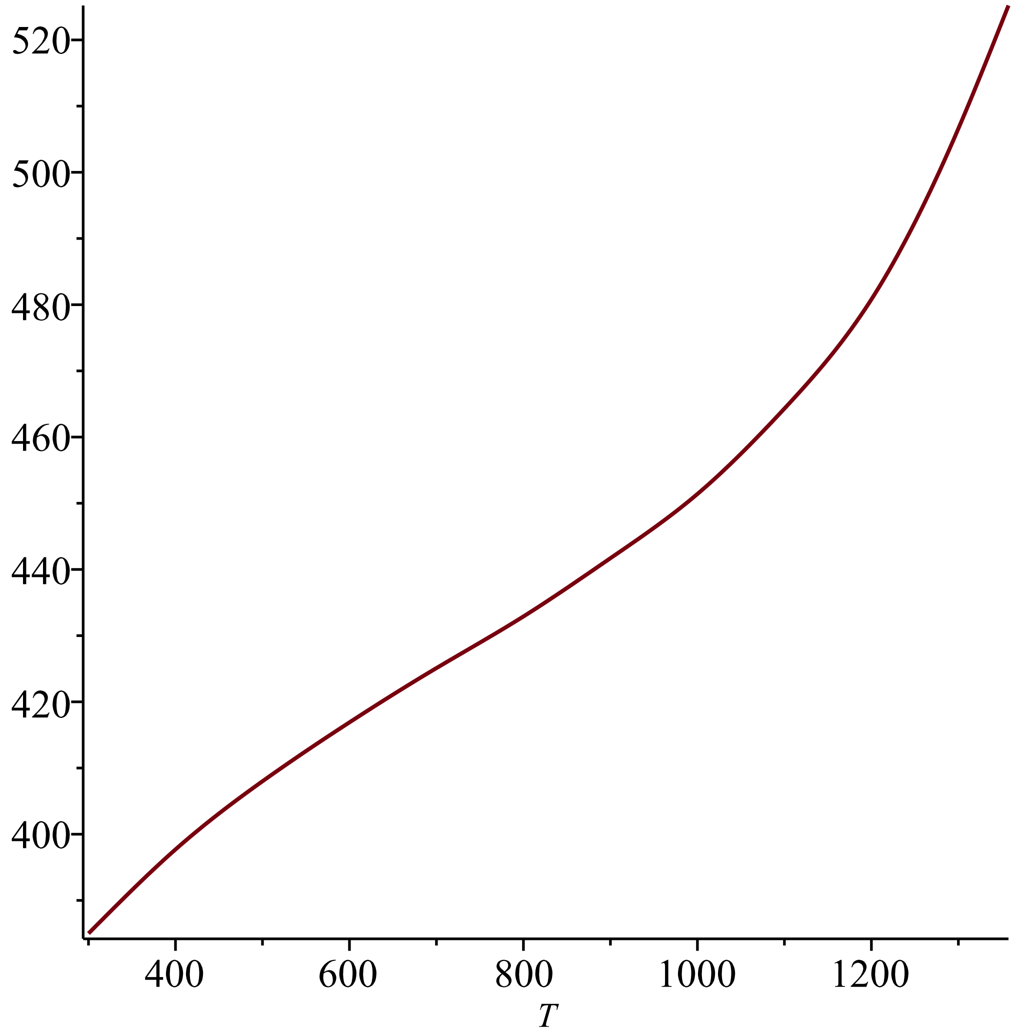
plot(*tab1_T*, *tab1_Cp*)



$with(CurveFitting) : c_p(T) := Spline(tab1\_T, tab1\_Cp, T, degree = 3) : c_p(T)$

$$\left\{\begin{array}{l}
345.242064496472 + 0.132526451678426\, T + 1.11022302462516\; 10^{-18}\, (T - 300)^2 - 5.52645167842621\; 10 \\
351.321161342741 + 0.115947096643148\, T - 0.000165793550352785\, (T - 400)^2 + 3.63225839213082\; 10 \\
361.157419125508 + 0.0936851617489832\, T - 0.0000568257985888604\, (T - 500)^2 + 9.97418109902893\; 1 \\
365.712646183448 + 0.0853122563609198\, T - 0.0000269032552917736\, (T - 600)^2 - 6.21930831742398\; 1 \\
370.453931034864 + 0.0780658128073378\, T - 0.0000455611802440456\, (T - 700)^2 + 4.49030521706672\; 1 \\
366.960406072217 + 0.0824244924097289\, T + 0.0000891479762679560\, (T - 800)^2 - 3.33929003652447\; 1 \\
360.487404201628 + 0.0902362175537467\, T - 0.0000110307248277781\, (T - 900)^2 + 7.86685492903114\; 1 \\
339.769362624715 + 0.111630637375284\, T + 0.000224974923043156\, (T - 1000)^2 - 5.12812967960009\; 10 \\
308.934643760373 + 0.141241232945115\, T + 0.000711310326551534\, (T - 1100)^2 + 0.0000016645663789 \\
234.314682986895 + 0.205404430844254\, T + 0.000570500946336230\, (T - 1200)^2 - 4.45452547787677\; 10 \\
108.616643218770 + 0.306141043677869\, T + 0.000436865181999927\, (T - 1300)^2 - 0.0000025281549884
\end{array}\right.$$

$plot\left(c_p(T),\ T = 300\ ..1357.6\right)$



$Q_{nagrev\_do\_T\_pl} := int\left(c_p(T),\ T = 300\ ..1357.6\right)$

$$4.660242040\ 10^5 \tag{19}$$

/

$c_p(1357)$

$$525.001217859185 \tag{20}$$

$c_{p\_exptrapotation} := c_p(1357) \cdot M_{molar\_sgs} \cdot 10^{-3}$

$$33.3617273900798 \tag{21}$$

$Q_{nagrev\_do\_T\_pl} \cdot M_{Cu\_sgs} \cdot 0.001$

$$0.6529699644 \tag{22}$$

T, °K	γ, 10^3 кг/м³	c_p, кдж/(кг·град)	λ, вт/(м·град)	ρ, 10^{-8} ом·м	α, 10^{-6} 1/град
83	9,00	0,259	480	—	—
293	8,93	0,381	395	1,68	16,70
373	8,90	0,399	392	2,34	17,10
573	8,84	0,422	373	3,89	17,98
873	8,70	0,456	344	5,76	19,52
1173	8,62	0,482	321	9,42	21,34
1356	8,51	0,533	—	9,89	22,31
1473	8,32	—	—	3,515	—

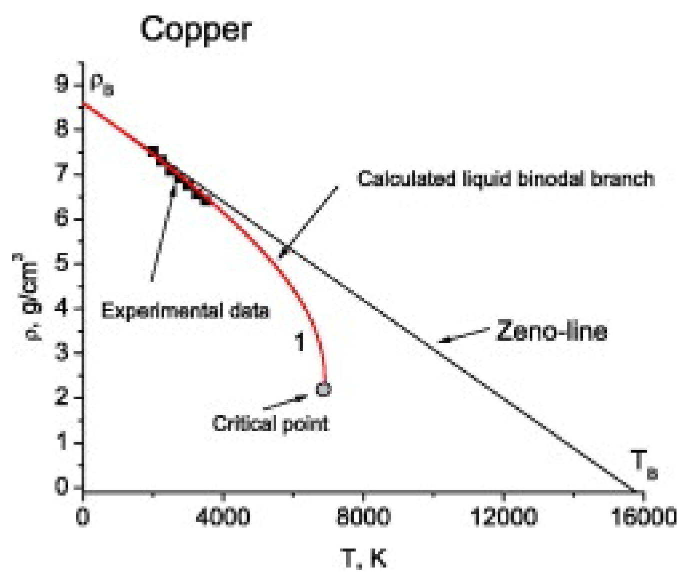
1357.6 K 8.00* / 3 -

1400 7,98 /3
1600 K 7.96 / 3

2 8 4 0

https://www.sciencedirect.com/science/article/abs/pii/S0009261408015790

The predictions of the critical point parameters for Al, Cu and W found from the correspondence between the critical point and unit compressibility line (Zeno line) positions



,

,

.

,

https://www.sciencedirect.com/science/article/abs/pii/S0009261408015790
Chemical Physics Letters 467 (2009) 318–322. The predictions of the critical point parameters for Al, Cu and W found from the correspondence between the critical point and unit compressibility line (Zeno line) positions. E.M. Apfelbaum *, V.S. Vorob’ev. Joint Institute for High Temperatures of Russian Academy of Science, Izhorskaya 13, Stroenie 2, 125412 Moscow, Russia

,

7093 1.95 This work
7620 1.4 Scaling [27] A.A. Likalter, Phys. Rev. B 53 (1996) 4386.
8390 2.4 Extrapolation [28] V.E. Fortov, A.N. Dremin, A.A. Leont’ev, Teplofizila vysokih temperatur 13
(1975) 984 (in Russian).

$T_i := 7093$

$$7093 \tag{23}$$

$\rho_{crit} := 1.95$

$$1.95 \tag{24}$$

$$V_{Cu\_sgs_{crit}} := \frac{M_{Cu\_sgs}}{\rho_{crit}}$$

$$0.0007185386277 \tag{25}$$

^ 3

$$R_i := 0.01 \cdot evalf\left(\left(\frac{3}{4 \cdot \pi} \cdot V_{Cu\_sgs_{crit}}\right)^{\frac{1}{3}}\right)$$

$$0.0005556318983 \tag{26}$$

( ) 745,0 (7,72) / ()

(. .) 8,92 /³

1356,55 K (1 083,4 °) 1083

2 567 ° 2877

. 13,01 / 3.11 / * 4.184 / = 13,01224

. 304,6 / 72,8 /* 4.184 / = 304,5952

24,44[2] /(K·) - 5,848 - 4,968 / * 4.184 / = 24,468032

7 , 1 ³ /

$$Q_{pl} := 13.01224 \cdot 10^{3} \cdot \nu_{Cu}$$

$$0.2869119109 \qquad \textbf{(27)}$$

$$Q_{isp} := 304.6 \cdot 10^{3} \cdot \nu_{Cu}$$

$$6.716243174 \qquad \textbf{(28)}$$

$$Q_{nagrev} := (7093 - 300) \cdot c_{p\_exptrapotation} \cdot \nu_{Cu}$$

$$4.99696902105744 \qquad \textbf{(29)}$$

1 5

8 0 0 . 1 1

.

: 1 5

( )

1 2 0 0 .

, 8 0 0

, 1 2 0 0 ,

.

( )

$$\nu = \frac{1}{T} = \sqrt{\frac{4\pi n_e e^2}{3m_e}}$$

$$n_e = \frac{3m_e}{4\pi e^2 T^2}$$

$$n_e := \frac{3 \cdot m_e}{4 \cdot \pi \cdot q_e^{2} \cdot (1.2 \cdot 10^{-3})^{2}}$$

$$5.883247344\ 10^{12} \qquad \textbf{(30)}$$

^ - 3

$$Q_{ionization} := 745 \cdot 10^{3} \cdot \nu_{Cu}$$

$$16.42679305 \qquad \textbf{(31)}$$

(4 . 9 9 8 2 0 8 1 0 5) (6 . 7 1 6 2 4 3 1 7 4
) + (4 5 0)

$$V_{Cu\_1atm} := \frac{\nu_{Cu} \cdot N_A \cdot k \cdot T_i}{10^5}$$

0.00001300352340 **(32)**

^ 3

$$V_{Cu\_450atm} := \frac{\nu_{Cu} \cdot N_A \cdot k \cdot T_i}{450 \cdot 10^5}$$

$2.889671867\ 10^{-8}$ **(33)**

$$V_{Cu_{crit}} := \frac{M_{Cu\_sgs}}{\rho_{crit}} \cdot 10^{-6}$$

$7.185386277\ 10^{-10}$ **(34)**

$$A := \int_{V_{Cu_{crit}}}^{V_{Cu\_1atm}} \frac{\nu_{Cu} \cdot N_A \cdot k \cdot T_i}{V} \, \mathrm{d}V$$

12.74801905 **(35)**

$$\int_{V_{Cu\_450atm}}^{V_{Cu\_1atm}} \frac{\nu_{Cu} \cdot N_A \cdot k \cdot T_i}{V} \, \mathrm{d}V$$

7.944174390 **(36)**

,

$$\Delta E := E_c - Q_{pl} - Q_{isp} - Q_{nagrev} - Q_{ionization} - A$$

93.8250637789426 **(37)**

$$\Delta t := \Delta E \cdot \frac{500 \cdot 10^{-6}}{E_c}$$

$$0.000347500236218306 \quad \textbf{(38)}$$

,

$$\Delta T := \frac{\Delta E}{c_{p\_exptrapotation} \cdot \nu_{Cu}}$$

$$1.27548050741264\ 10^{5} \quad \textbf{(39)}$$

,

$$T_e := \Delta T + T_i$$

$$1.34641050741264\ 10^{5} \quad \textbf{(40)}$$

1 1 , 1 6 0 4 5 2 2 1 (6 7) ·1 0 ^ 4 (.
) .

$$\frac{T_e}{1.16045221 \cdot 10^{4}}$$

$$11.6024640725366 \quad \textbf{(41)}$$

1 / 3
5

$$dNdv_0(m, v, T) := 4 \cdot \pi \cdot N_i \cdot \left(\frac{m}{2 \cdot \pi \cdot k \cdot T} \right)^{\frac{3}{2}} \cdot v^2 \cdot \exp\left(- \frac{m \cdot v^2}{2 \cdot k \cdot T} \right) :$$

$$dNdv2_0(m, v2, T) := 4 \cdot \pi \cdot N_i \cdot \left(\frac{m}{2 \cdot \pi \cdot k \cdot T} \right)^{\frac{3}{2}} \cdot v2 \cdot \exp\left(- \frac{m \cdot v2}{2 \cdot k \cdot T} \right)$$

$$(m, v2, T) \rightarrow \pi N_i \sqrt{2} \left(\frac{m}{\pi k T} \right)^{3/2} v2\, \mathrm{e}^{-\frac{1}{2} \frac{v2\, m}{k T}} \quad \textbf{(42)}$$

$$\frac{1}{N_i} \int_0^{\infty} dNdv_0(m_e, v, T_e)\, \mathrm{d}v$$

$$1.000000000 \quad \textbf{(43)}$$

$$\frac{1}{N_i} \int_0^{\infty} dNdv_0(m_{Cu}, v, T_e)\, \mathrm{d}v$$

$$1.000000000 \quad \textbf{(44)}$$

$$V_{Cu\_sgs_{crit}} \cdot 10^{-6}$$

$$7.185386277\ 10^{-10} \tag{45}$$

$$\int_0^{R_i} 4 \cdot \pi \cdot r^2 \, \mathrm{d}r$$

$$7.185386273\ 10^{-10} \tag{46}$$

R_i

$$n_i := \frac{N_i}{\int_0^{R_i} 4 \cdot \pi \cdot r^2 \, \mathrm{d}r}$$

:

$$1.847979889\ 10^{28} \tag{47}$$

$$v_T(m, T) := \sqrt{\frac{2 \cdot k \cdot T}{m}}$$

$$(m, T) \rightarrow \sqrt{\frac{2\ k\ T}{m}} \tag{48}$$

$$v_T(m_e, T_i)$$

$$4.636895888\ 10^{5} \tag{49}$$

$$v_T(m_e, T_e)$$

$$2.02023137241212\ 10^{6} \tag{50}$$

$$v_T(m_{Cu}, T_i)$$

$$1357.554508 \tag{51}$$

$$v_T(m_{Cu}, T_e)$$

$$5914.67712890453 \tag{52}$$

:

$\alpha := 0.00025$:

$$v_{0r}(r_0, R_i, m, T) := \alpha \cdot \frac{r_0}{R_i} \cdot v_T(m, T)$$

$$(r_0, R_i, m, T) \rightarrow \frac{\alpha\, r_0\, v_T(m, T)}{R_i} \tag{53}$$

$$v_{0r}(r_0, R_i, m, T)$$

$$2.364338738\ 10^{-12}\, r_0 \sqrt{\frac{T}{m}} \tag{54}$$

r_0

$$a_{0r}(r_0, R_i, m, T) := \frac{\Delta T}{\Delta t} \cdot \alpha \cdot \frac{r_0}{R_i} \cdot \frac{\mathrm{d}}{\mathrm{d}\,T}\ v_T(m, T)$$

$$(r_0, R_i, m, T) \rightarrow \frac{\Delta T\, \alpha\, r_0 \left(\frac{\partial}{\partial T}\ v_T(m, T) \right)}{\Delta t\, R_i} \tag{55}$$

$$a_{0r}(r0, R_i, m, T)$$

$$\frac{0.000433908765869441\ r0}{\sqrt{\frac{T}{m}}\ m} \tag{56}$$

$$r(t, r_0, R_i, m, T) := r_0 + v_{0r}(r_0, R_i, m, T) \cdot t + \frac{a_{0r}(r_0, R_i, m, T) \cdot t^2}{2}$$

$$(t, r_0, R_i, m, T) \rightarrow r_0 + v_{0r}(r_0, R_i, m, T)\ t + \frac{1}{2}\ a_{0r}(r_0, R_i, m, T)\ t^2 \tag{57}$$

$$r(t, r_0, R_i, m, T)$$

$$r_0 + 2.364338738\ 10^{-12}\, r_0 \sqrt{\frac{T}{m}}\ t + \frac{0.000216954382934720\ r_0\, t^2}{\sqrt{\frac{T}{m}}\ m} \tag{58}$$

$$v_r(t, r_0, R_i, m, T) := v_{0r}(r_0, R_i, m, T) + a_{0r}(r_0, R_i, m, T) \cdot t$$

$$(t, r_0, R_i, m, T) \rightarrow v_{0r}(r_0, R_i, m, T) + a_{0r}(r_0, R_i, m, T)\ t \tag{59}$$

$$v_r(t, r_0, R_i, m, T)$$

$$2.364338738\ 10^{-12}\, r_0 \sqrt{\frac{T}{m}} + \frac{0.000433908765869441\, r_0\, t}{\sqrt{\frac{T}{m}}\; m} \tag{60}$$

$$tzap\left(t, r_0, R_0, R_i, m, T, \theta\right) := solve\left(c^2\, \left(t - t_{zap}\right)^2 = R_0^{\,2} - 2 \cdot R_0 \cdot r\left(t_{zap}, r_0, R_i, m, T\right) \cdot \cos(\theta) + r\left(t_{zap}, r_0, R_i, m, T\right)^2, t_{zap}\right)$$

$$\left(t, r_0, R_0, R_i, m, T, \theta\right) \rightarrow solve\left(c^2\, \left(t - t_{zap}\right)^2 = R_0^{\,2} - 2\, R_0\, r\left(t_{zap}, r_0, R_i, m, T\right) \cos(\theta) + r\left(t_{zap}, r_0, R_i, m, T\right)^2, t_{zap}\right) \tag{61}$$

$$tzap\left(t, r_0, R_0, R_i, m, T, \theta\right)$$

$$\begin{aligned}
RootOf\Big(& 1176730106864631156355898046081960\, r_0^{\,2}\, _Z^4 \\
& + 25647682597572264159910332\, T\, r_0^{\,2}\, _Z^3 \\
& - \Big(108477191467360140000000000000000000000 \sqrt{\frac{T}{m}}\, R_0\, m\, r_0 \cos(\theta) \\
& - 108477191467360140000000000000000000000 \sqrt{\frac{T}{m}}\, m\, r_0^{\,2} \\
& - 1397524417001858161\, T^2\, r_0^{\,2} \\
& + 2246887946842044100000000000000000000000000000000000000\, T\, m \Big)\, _Z^2 \\
& - \Big(11821693690000000000000000000 \left(\frac{T}{m}\right)^{3/2} R_0\, m^2\, r_0 \cos(\theta) \\
& - 11821693690000000000000000000 \left(\frac{T}{m}\right)^{3/2} m^2\, r_0^{\,2} \\
& - 4493775893684088200000000000000000000000000000000000000\, T\, m\, t \Big)\, _Z \\
& - 500000000000000000000000000000000000000000 \cos(\theta)\, T\, m\, R_0\, r_0 \\
& + 250000000000000000000000000000000000000000\, R_0^{\,2}\, T\, m \\
& + 250000000000000000000000000000000000000000\, T\, m\, r_0^{\,2} \\
& - 2246887946842044100000000000000000000000000000000000000\, T\, m\, t^2 \Big)
\end{aligned} \tag{62}$$

$$R_{zap}(t_{zap}, r_0, R_0, R_i, m, T, \theta) := \sqrt{R_0^{\,2} - 2 \cdot R_0 \cdot r(t_{zap}, r_0, R_i, m, T) \cdot \cos(\theta) + r(t_{zap}, r_0, R_i, m, T)^2}$$

$$(t_{zap}, r_0, R_0, R_i, m, T, \theta) \rightarrow \sqrt{R_0^{\,2} - 2\, R_0\, r(t_{zap}, r_0, R_i, m, T) \cos(\theta) + r(t_{zap}, r_0, R_i, m, T)^2} \tag{63}$$

$$R_{zap}(t_{zap}, r_0, R_0, R_i, m, T, \theta)$$

$$\left(R_0^{\,2} - 2\, R_0 \left(r_0 + 2.364338738\ 10^{-12}\, r_0 \sqrt{\frac{T}{m}}\ t_{zap} + \frac{0.000216954382934720\, r_0\, t_{zap}^{\,2}}{\sqrt{\frac{T}{m}}\ m} \right) \cos(\theta) + \left(r_0 + 2.364338738\ 10^{-12}\, r_0 \sqrt{\frac{T}{m}}\ t_{zap} + \frac{0.000216954382934720\, r_0\, t_{zap}^{\,2}}{\sqrt{\frac{T}{m}}\ m} \right)^2 \right)^{1/2} \tag{64}$$

$$R_{zap}(tzap(t, r_0, R_0, R_i, m, T, \theta), r_0, R_0, R_i, m, T, \theta) :$$

,

$$K_{zap}(t_{zap}, r_0, R_0, R_i, m, T, \theta) := R_{zap}(t_{zap}, r_0, R_0, R_i, m, T, \theta) - \frac{v_r(t_{zap}, r_0, R_i, m, T)}{c} \cdot \left(R_0 \cdot \cos(\theta) - r(t_{zap}, r_0, R_i, m, T) \right)$$

$$(t_{zap}, r_0, R_0, R_i, m, T, \theta) \rightarrow R_{zap}(t_{zap}, r_0, R_0, R_i, m, T, \theta) - \frac{v_r(t_{zap}, r_0, R_i, m, T)\ \left(R_0 \cos(\theta) - r(t_{zap}, r_0, R_i, m, T) \right)}{c} \tag{65}$$

$$K_{zap}(t_{zap}, r_0, R_0, R_i, m, T, \theta)$$

$$\left(R_0^{\,2} - 2\, R_0 \left(r_0 + 2.364338738\ 10^{-12}\, r_0 \sqrt{\frac{T}{m}}\ t_{zap} + \frac{0.000216954382934720\, r_0\, t_{zap}^{\,2}}{\sqrt{\frac{T}{m}}\ m} \right) \cos(\theta) + \left(r_0 + 2.364338738\ 10^{-12}\, r_0 \sqrt{\frac{T}{m}}\ t_{zap} + \frac{0.000216954382934720\, r_0\, t_{zap}^{\,2}}{\sqrt{\frac{T}{m}}\ m} \right)^2 \right)^{1/2} - \frac{1}{299792458} \left(2.364338738\ 10^{-12}\, r_0 \sqrt{\frac{T}{m}} \right. \tag{66}$$

$$+\frac{0.000433908765869441\, r_0\, t_{zap}}{\sqrt{\frac{T}{m}}\, m}\Bigg)\Bigg(R_0 \cos(\theta) - r_0 - 2.364338738\ 10^{-12}\, r_0 \sqrt{\frac{T}{m}}\, t_{zap}$$

$$-\frac{0.000216954382934720\, r_0\, t_{zap}^{\ 2}}{\sqrt{\frac{T}{m}}\, m}\Bigg)$$

$K_{zap}\left(tzap\left(t, r_0, R_0, R_i, m, T, \theta\right), r_0, R_0, R_i, m, T, \theta\right)$:

r ,

R_0

r

R_0 **(67)**

$$\rho\left(q, N_i, R_i\right) := q \cdot \frac{N_i}{\int_0^{R_i} 4\cdot\pi\cdot r^2 \,\mathrm{d}r}$$

$$\left(q, N_i, R_i\right) \rightarrow \frac{q\, N_i}{\int_0^{R_i} 4\,\pi\, r^2 \,\mathrm{d}r} \tag{68}$$

$$\varphi\left(\sigma_{r_0}, t, r_0, R_0, m, T\right) := \int_0^{\pi} \frac{2\cdot\pi\cdot\ r\left(t, r_0, R_i, m, T\right)^2 \cdot \sin(\theta)\cdot\sigma_{r_0}}{K_{zap}\left(tzap\left(t, r_0, R_0, R_i, m, T, \theta\right), r_0, R_0, R_i, m, T, \theta\right)}\,\mathrm{d}\theta :$$

$$\varphi_{R_0}\left(t, R_0, m, T, q, N_i, R_i\right) := \int_0^{R_i} \varphi\left(\rho\left(q, N_i, R_i\right), t, r_0, R_0, m, T\right)\,\mathrm{d}r_0$$

$$\left(t, R_0, m, T, q, N_i, R_i\right) \rightarrow \int_0^{R_i} \varphi\left(\rho\left(q, N_i, R_i\right), t, r_0, R_0, m, T\right)\,\mathrm{d}r_0 \tag{69}$$

$evalf\left(subs\left(t=0, R_0=0.1, q=q_e, m=m_{e,\_}T=T_i, \varphi_{R_0}\left(t, R_0, m, T, q, N_i, R_i\right)\right)\right)$

$$A_{R_0} := \int_0^{\pi} \frac{2 \cdot \pi \cdot r\left(t, r_0, R_i, m, T\right)^2 \cdot \sin(\theta) \cdot \sigma\left(r_0\right) \cdot \left(v_r\left(t_{zap}, r_0, R_i, m, T\right) \cdot \cos(\theta)\right)}{K_{zap}\left(tzap\left(t, r_0, R_0, R_i, m, T, \theta\right), r_0, R_0, R_i, m, T, \theta\right)} \, d\theta :$$