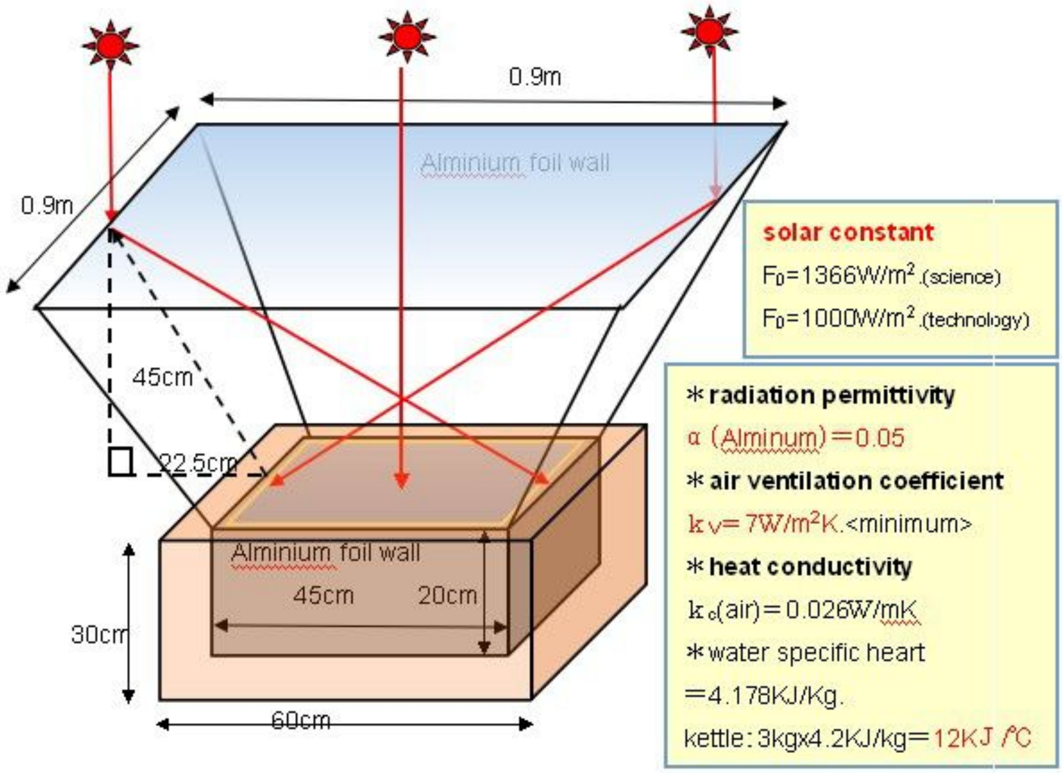
4R-SOLAR HEAT BOX 2014/10/25,2015/3/22



Parabola Solar Heater can get strong heat with less heat up time,but expensive, sensitive to the solar direction,.and rather danger for naked eye(→sun glass).
http://www.solarcooker-at-cantinawest.com/parabolic_solar_cooker_solar_burner.html
Box type heater with a reflector plate is easy,but heat up time is longer.
http://solarcooking.wikia.com/wiki/Minimum_Solar_Box_Cooker
Author tried to gain merits of both method,which is **4 reflector plate with inner heat shield box**(above fig).It can scarcely get **over 100℃ for 3kg water in a kettle** in **fine winter day** in **about 2~3 hours**. **Rotational setting** is effective to get max T,but rather inconvenient.

Input heat is proportional to **input mouth area**(0.9mx0.9m),while **loss heat output** is rather complicated due to **surface temperature distribution** of outer shield box.
The loss heat is mainly due to **random wind ventilation of the box surface**(highest temperature distribution in especially **top input glass surface** and the frame portion).
Bottom and side wall temperature may be lower due to double box shield method.
Water boiling is most expensive,so the cost is reduced,**but not nothing in cloudy days**
Aim at here is not recommending solar set at here,but **theoretical heat equations** which are useful to estimate the performance{**max T,heat up time,volume of load**}.

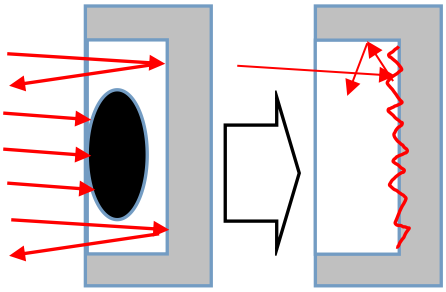
[1]：Heat Account.

(1)**Max Solar Heat input**≡J_S=0.9mx0.9mx(1000W/m^2;1360W/m^2)=**800**W.

Total Heat Input Mouth Area: S_S=0.9mx0.9m . <<Inner Box Mouth=0.45m×0.45m>

＊This is decisive element determining **max T** and heat up time= τ .Of course,larger is better,while larger increases damage risk by strong wind .

＊＊**direct return loss** by reflection from inner heat box wall.



The flat reflection wall is not good,so **back wall** should be random face for making **random reflection** not to go out<random winding lines>. ***Black wall*** is best to absorb,however **higher wall temperature** causes more heat loss.

(2)**Max Heat Dissipation output**≡J_D=J_R+J_V+J_{cd}=**800**W(at max temperature~**105** ℃).

＊Inner Box Surface Area: S_{inner}=2×0.45×0.45+4x0.45x0.2=0.77m^2.

Larger box volume increases heat loss and no utilizable heat capacity.

＊Outer Box Surface Area: S_{outer}=2×0.6×0.6+4x0.6x0.3=1.44m^2.

Note heat loss is entirely due to outer box surface temperature=T(S_{outer}).Especially top surface= S_{bt}(top glass and top surface frame)are mot serious.

(a)**surface air ventilation loss**: {κ_v=7W/m^2℃ in room,but larger in **wind** field }

J_{vbt}=$S_{bt}\,\kappa_v$(T_{bt}−T_E)=(0.6mx0.6m)x2.0x7W/m^2℃x80℃~400W.....top surface

J_{vbs}=$S_{bs}\,\kappa_v$(T_{bs}−T_E)=(0.6mx0.6m+4x0.6x0.3)x2.0x7W/m^2℃x20℃~300W..side wall

☞:The value "2.0" is author's coarse estimation for weak wind velocity<10m/s.

☞:In strong windy days,temperature can not reach 100℃,but such as about 70℃.

(b)**Al surface radiation loss**: {α =0.05} J_R= S α σ<T_B^4−T_E^4>. σ =5.67x10^{-8} J /m^{2}K^4

J_{Rbt}=(0.6mx0.6m)x0.05x5.67x10^{-8}<(273+110)^4−(273+10)^4)>=15W.

J_{Rbs}=(0.6mx0.6m+4x0.6x0.3)x0.05x5.67x10^{-8}<(273+30)^4−(273+10)^4)>=6W.

☞:Thus **surface radiation loss** is rather weak by {α =0.05 for Al}.Neglecting radiation loss would not exceed over **10% error** in about 100℃.This is **approximation** in the report.

(c)**Heat leakage air flow from top glass frame is not counted in above calculation.**

Note top glass can **not completely shield inner air**,but some degree is leaking at anytime.

This heat amount may be serious.~100W?

(d)**Thickness of Top Input Glass<5mm→8mm>.**

This is the highest temperature surface,which is expected less heat output.

Top glass thickness is dominant to get **higher max temperature**.

$J_{vbt} = S_{bt} \kappa_V (T_{bt} - T_E) =$ (0.6mx0.6m)x2.0x7 W/m²℃x80℃～400W.....top surface

$J_{cbt} = S_{bt} \kappa_C (T_{bi} - T_{bt})/d =$ 400W <<heat transfer from in to out by **conduction**>>

{κ_C=0.55～0.75W/mK; S_{bt}=0.45mx0.45m; d=0.005m}

$(T_{bi} - T_{bt}) = d \times J_{cbt} / S_{bt} \kappa_C$ = 14～19℃ (d=0.005m),

$G \equiv (d+\Delta d)/d$、→ G=1.6、$(T_{bi} - T_{bt})$ = 22～30℃

(e)**Heat transfer from inner box to outer one is air ventilation at inner heat box.**

＊Inner Box side Surface Area: $S_{inner\text{-}s}$ = 0.45×0.45+4x0.45x0.2=0.57m².

＊Outer Box side Surface Area: $S_{outer\text{-}s}$ = 0.6×0.6+4x0.6x0.3=1.1m².

$J_{cibs} = S_{inner\text{-}s} \kappa_V (T_{bi} - T_{bt})$ = 0.57m²×7×(100-30)=280W.

$J_{cibs} = S_{inner\text{-}s} \kappa_V (T_{bi} - T_{bt})$ = 0.57m²×7×(110-30)=300W.

$J_{cbt} = S_{bt} \kappa_C (T_{bi} - T_{bt})/d$ = (0.57+1.1)/2×0.026×(110-30)/0.1m=17W.

＊**conduction heat transfer** is very weaker than that of ventilation.

(f)**weaken air ventilation between inner and outer box space**.

Inner box should be shielded to **reduce air venation**,which could be accomplished by inserting bubble polystyrene,or something lower conductivity.Then note heat box temperature exceeds over 100℃,so those must be tough for heating.

(g)Following are **summary table** of this report.

Max Heat Input Input mouth area = S_S	$F_0 S_S \equiv J_S (= J_D$.<at max temperature>). ＊
Max Heat Output(by ventilation) $= J_{DR} + J_{DV} \fallingdotseq J_{DV} \equiv J_D$ $J_{DR} \fallingdotseq 0$ radiation loss	$J_{DV} = \oint dS(s) \kappa_V(s)(T(s) - T_E)$ $\equiv S_B \kappa_V(s')(T(s') - T_E)$ $\equiv K(T_{max} - T_E)$. → $K = J_S/(T_m - T_E)$.
Max temperature	$T_H(\infty) = J_S/K$.
Heat up time constant :	$\tau = C_H/K$. **<**C_H=heat loadC_L+heat boxC_B**>**

(3) Time Response of Heater Temperature.

Solar heater is completely free,but exception is **not quick action** in small solar input.

This section is very important to get **better design parameters** of solar heater you wish.

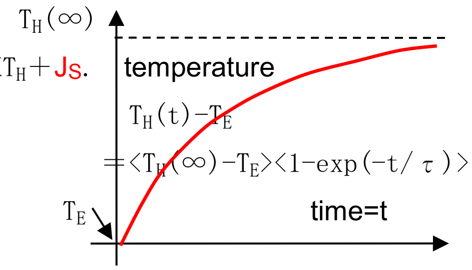
(a) **heat capacity of heater × temperature rise/sec = {heat-input − heat-output}/sec**

$C_H(dT_H/dt) = J_S - J_D$. . . . . <<**heat account equation**>>.

(b) $J_D \fallingdotseq K\langle T_H - T_0\rangle$. . . . . (2)(a). . . . . . <<see more details in (4)>>

☞ : **Linear heat loss approximation**(air ventilation loss in surface of outer box).

(c) J_S = (**constant average assumption**).



$C_H(dT_H/dt) = J_S - K\langle T_H - T_0\rangle = -KT_H + (KT_0 + J_S) \equiv -KT_H + J_S$.

$dT_H/dt = -(K/C_H)T_H + (J_S/C_H) \equiv -T_H/\tau + T'_H(0)$.

$\rightarrow dT_H/dt + T_H/\tau = T'_H(0)$.

$\rightarrow d[T_H \exp(t/\tau)]/dt = T'_H(0)\exp(t/\tau)$.

$\rightarrow T_H \exp(t/\tau) = \tau T'_H(0)\exp(t/\tau) + C$.

(d) **Heat up time function**.

$T_H(t) = T_E + (T_H(\infty) - T_E)\langle 1 - \exp(-t/\tau)\rangle$. $\rightarrow$ $t(T) = -\tau \ln(1 - \langle T - T_E\rangle / \langle T_H(\infty) - T_E\rangle)$.

example) $\langle T-T_E\rangle/\langle T_H(\infty)-T_E\rangle = 100/120$, → $t(T) = -\tau \ln(1/6) = 1.8\tau$

$\langle T-T_E\rangle/\langle T_H(\infty)-T_E\rangle = 100/105$, → $t(T) = -\tau \ln(5/105) = 3\tau$

＊<in the below,yellow portion is authors estimation>

(e) **Heat up time constant** : $\tau = C_H/K\ (= C_H\langle T_H(\infty) - T_E\rangle / J_S)$.

example) $\tau \equiv C_H/K \sim (12KJ/℃ + 8KJ/℃)/(7W/℃) = 0.8h$, → $3\tau = 2.4h$.

<<☞ : $C_H = 12KJ/3kg$-water>>

: Larger **heat load** = C_H takes longer heat up time = **3** τ .

C_H = heat capacity of {heat load ≡ C_L + heat box ≡ C_B}.

☞ : caution, τ is not heat up time you want(such as T = 100℃),but is **time of final highest temperature**.**Stronger J_S** can make shorter time,and **larger C_H** makes longer time..

(f) **max temperature** : $T_H(\infty) = J_S/K\ (= J_S\tau/C_H)$.

$T_H(\infty) = \tau T'_H(0) = (C_H/K)(J_S/C_H) = J_S/K \sim$ 700W/(8W/℃),800W/(9W/℃) ~ 90℃. <<$T_H(t=0) \equiv$>>.

Larger air ventilation = K makes lower **max temperature** = $T_H(\infty)$.

☞ : $K = \tau / C_H = J_S / \langle T_H(\infty) - T_E\rangle \fallingdotseq 7 \sim 20W/℃$?.

(g) $T'_H(0) = J_S/C_H$.

(4)**As for the parameter “K” in** “(3)(b)$J_D \fallingdotseq K\langle T_H - T_0\rangle$. . . . . (2)(a)” .

This K is most important parameter determining **max temperature of heat box:**$T_H(\infty) = J_S/K$ and heat up time : $\tau = C_H/K$. .K is originally due to following form.

[1](2)(a)**surface air ventilation loss**:{ $\kappa_v = 7W/m^2℃$ in room,but larger in field with **wind**}

$J_{vbt} = S_{bt}\,\kappa_v(T_{bt} - T_E) =$(0.6mx0.6m)x2.0x7 W/m²℃x90℃～450W

$J_{vbs} = S_{bs}\,\kappa_v(T_{bs} - T_E) =$(0.6mx0.6m＋4x0.6x0.3)x2.0x7 W/m²℃x20℃～300W

The strict form is as follows.Then a kernel problem is wind dependent parameter＝κ_v.

$J_{vs} = \oint dS(s)\,\kappa_v(s)\,(T(s) - T_E) = S_T\langle \kappa_v(s')\,(T(s') - T_E)\rangle \equiv K(T_m - T_E)$.

＝total surface area × $\kappa_v(s')$ ×<surface s'temperature at max box T_m －minimum T_E>

＊$dS(s)$＝differential surface area of local portion s.

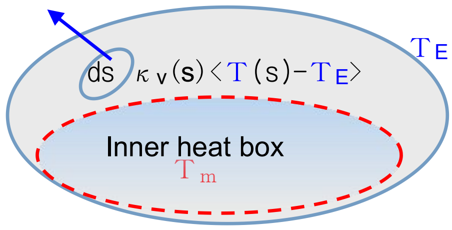
$\oint dS(s) = S_T$<total area of surface>.

＊ $\kappa_v(s) = \kappa_v$ at local surface portion s.

$\kappa_v(s) = 7W/m^2℃$ × (1～3?)by wind.

＊maximum T_s＝maximum T of surface portion＝s.

＊Minimum T＝environmental air T.



＊$K \equiv S_T\langle \kappa_v(s')\,(T(s') - T_E)\rangle/(T_m - T_E) = J_S/(T_m - T_E)$.

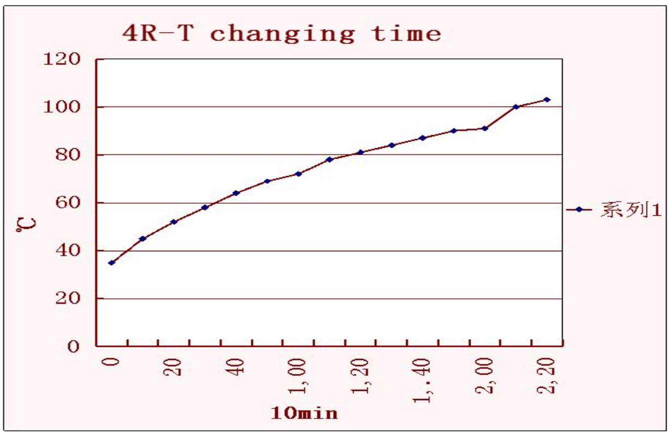
$(T(s') - T_E)\rangle/(T_m - T_E) \fallingdotseq 0.2～1.$ $\kappa_v(s) = 1～3? \times 7W/m^2℃$ by wind.

example calculation)

$S_T = 1.44m^2$.; $(T(s') - T_E)\rangle/(T_m - T_E) \fallingdotseq 0.4$. $\kappa_v(s) \fallingdotseq 2 \times 7W/m^2℃$ by wind.

→$K \equiv S_T\langle \kappa_v(s')\,(T(s') - T_E)\rangle/(T_m - T_E) \fallingdotseq 8.1W/℃$, or 750W/(100-10)≒8.3W/℃.

(5)**Time response in measured value.** ２０１５－１－１４



environmental condition

air temperature

T_E～10℃

wind velocity

V_W～almost nothing.

solar angle

almost perpendicular

by rotational base operation

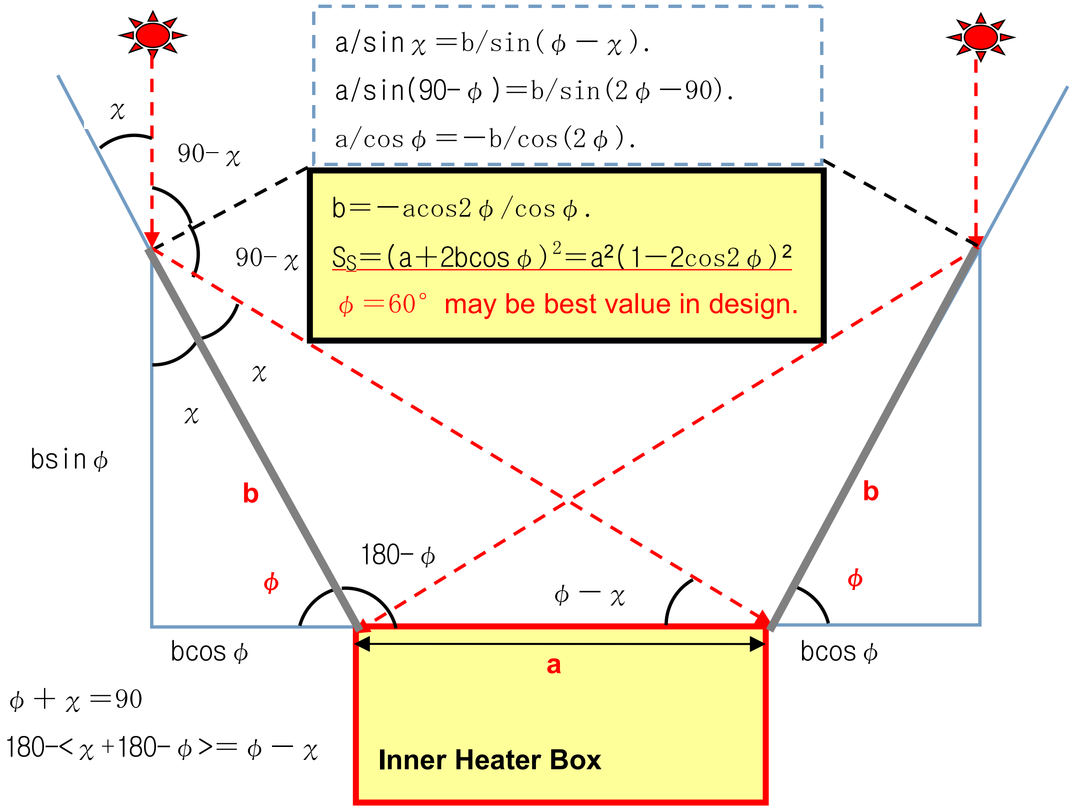
Note above **100℃** is very calm boiling point,but not strong stirring due to $J_S \fallingdotseq J_D$.

The experiment is most cold season July in northern hemisphere latitude 43(Tokyo).

Therefore another warmer season would be more quick heat up time.

[2]：Calculation on Reflector Angle and Reflector Size.

How to determine design parameters of {a=box size,b=reflector length,and ϕ}in order to optimize **effective heat input mouth area**$= S_S(\phi; a, b)$?.



∗optimization on larger mouth vs less volume.

Getting **boiling temperature** for 2 kettles is aim(as for author),so it should be large..

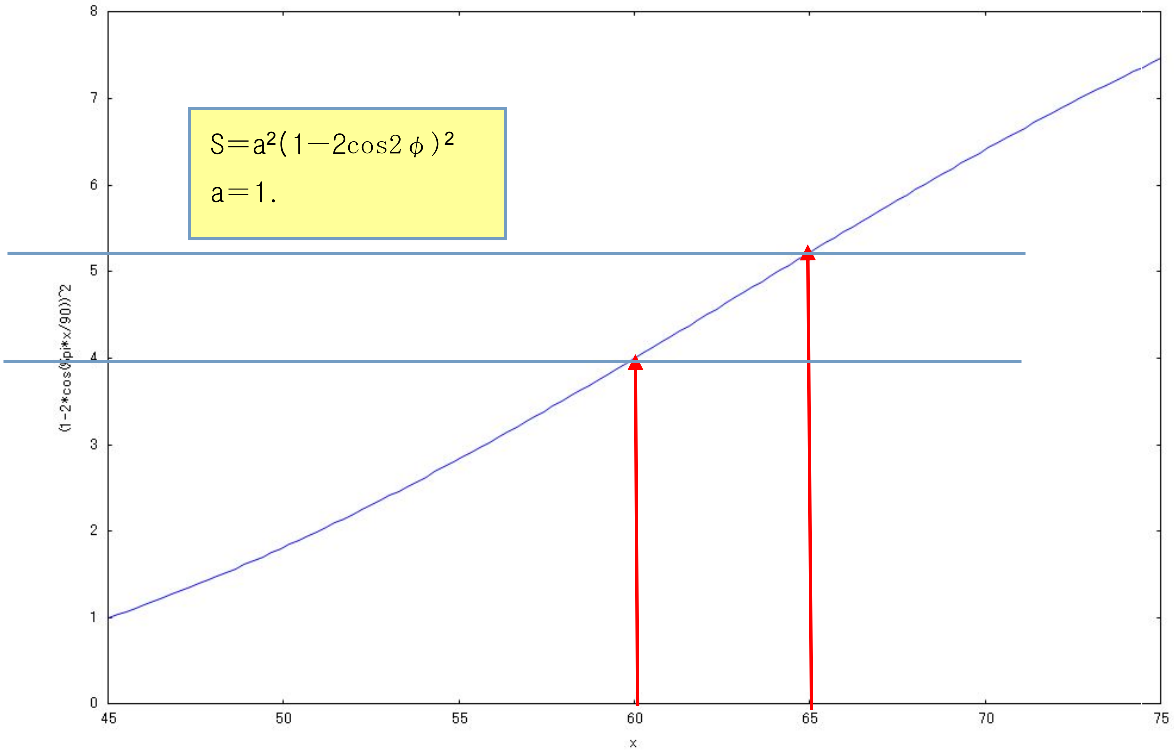
While,**plywood** area is 180cm×90cm,which should be used without loss.And also the solar set must not be damaged by **strong wind**,so it should be small.

Then author concluded $\phi=60°$, a=box size=45cm,,b=reflector length=45cm.

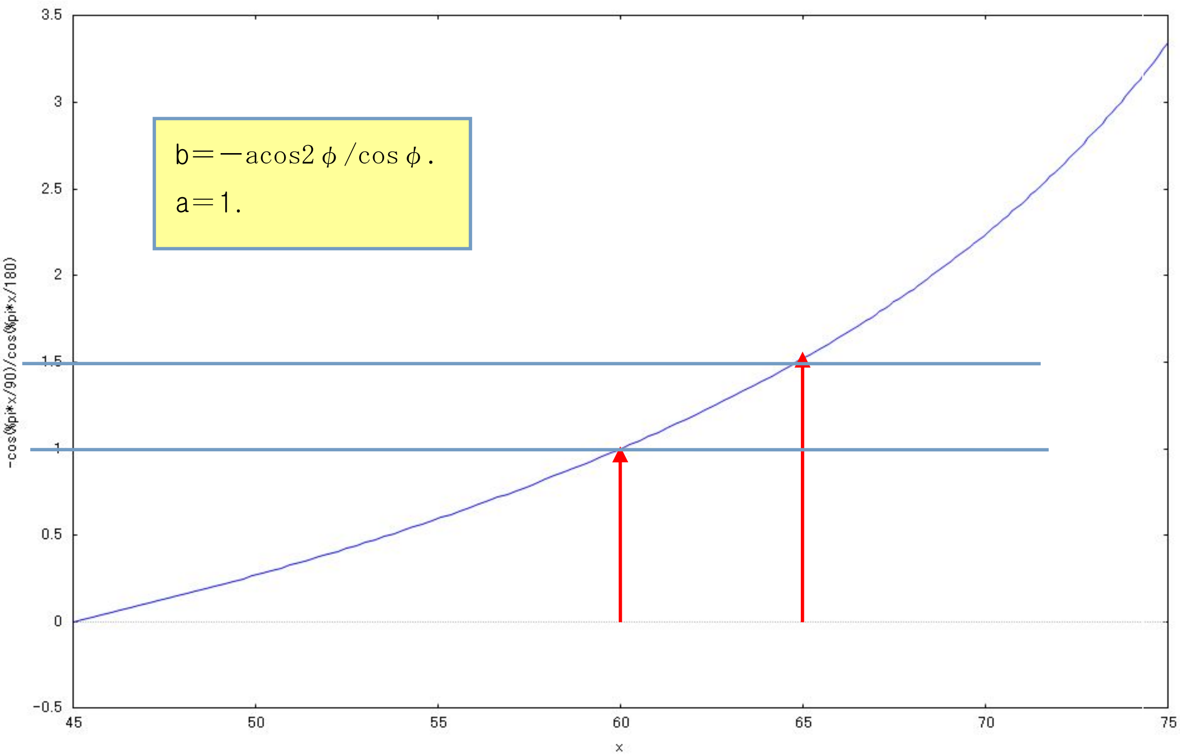
See plot 2. $\phi=60°$ is with b＝45cm、while $\phi=65°$ is with b＝67.5m、

The latter b＝67.5m becomes larger while mouth increasing is 25%<See plot 1.>.

1. plot2d((1-2*cos(4*x*%pi/360))^2,[x,45,75]);

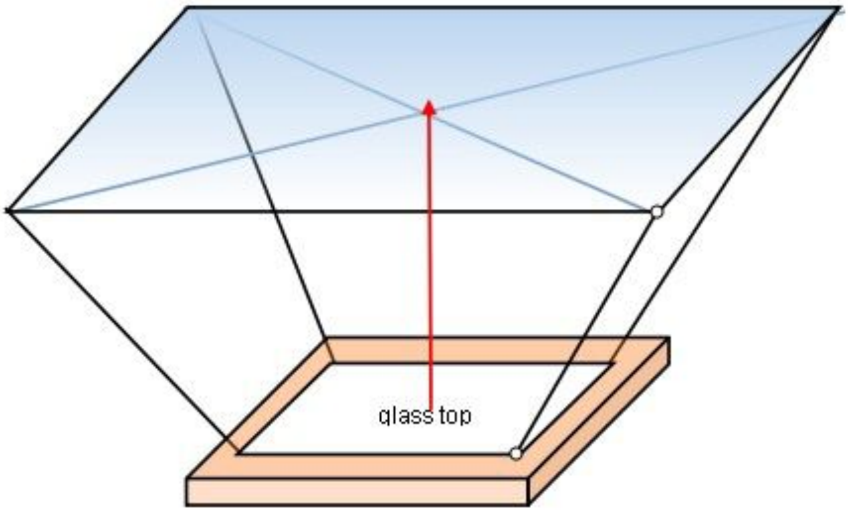


2. plot2d(-cos(4*x*%pi/360)/cos(2*x*%pi/360),[x,45,75]);

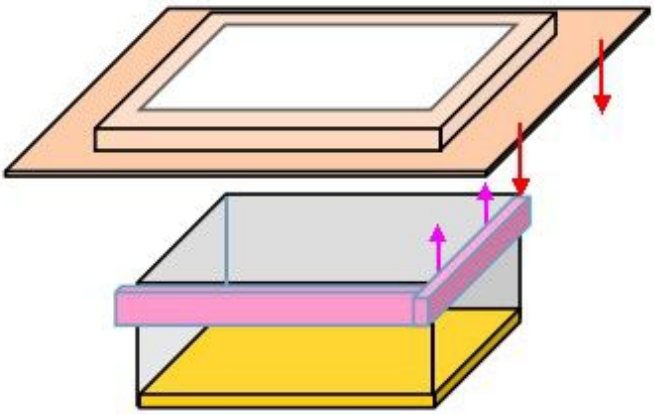


over whole view for fabrication sequence<bottom to top>. 2014/11/20

Reflectors

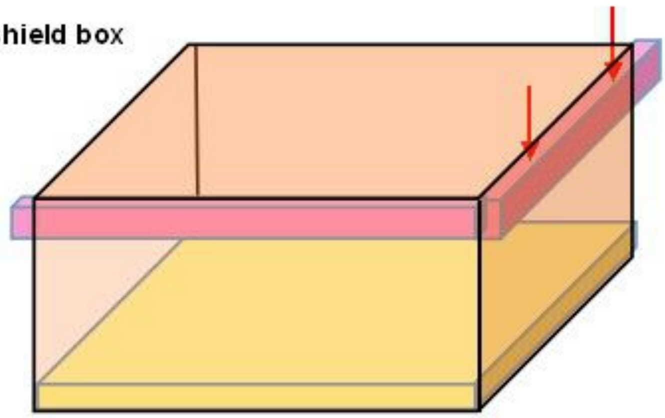


inner heat box junction

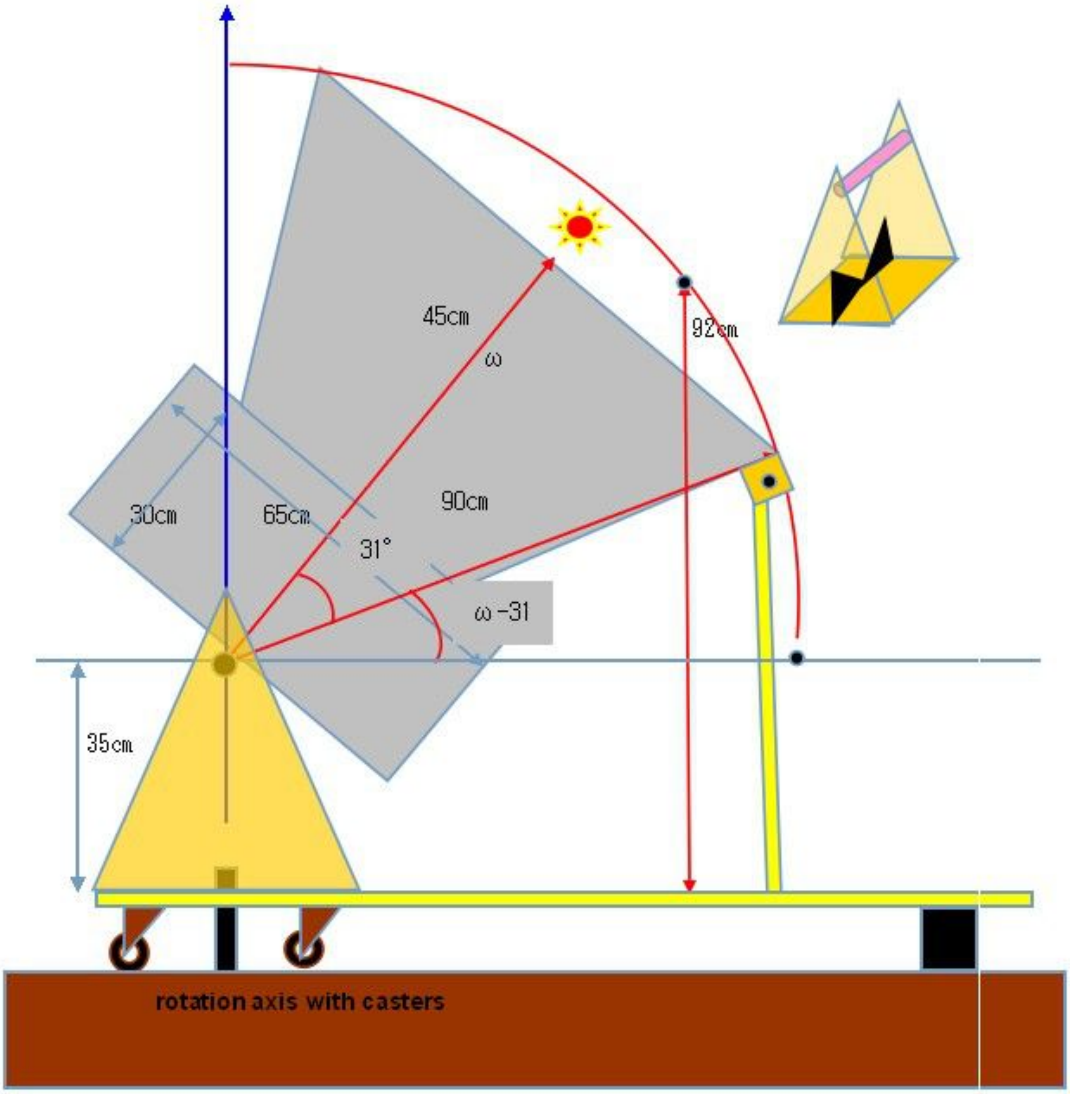


outer shield box

drilling



Rotational base.



ω＝	30	40	50	60	70
Y=90sin(ω-31)	0	14	29.3	43.6	57
L(stick)	35	49	64.3	79	92