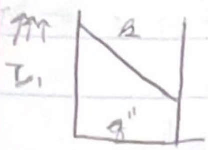
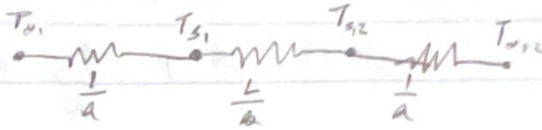
HW#7

9.1) $L = 75e^{-3}$ m $T_{\infty_1} = 200°C$ h_{min} & max h from 1.1 find min & max heat flux

$k = 2.5$ W/m·K $T_{\infty_2} = 100°C$ for i) free conv in gas ii) free conv in liquids iii) forced conv in gas iv) forced conv in liquid v) conv w/ phase change



use thermal resistance

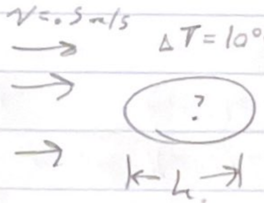


$$q'' = \frac{T_{\infty_1} - T_{\infty_2}}{\frac{1}{h} + \frac{L}{k} + \frac{1}{h}}$$

calculated in python

	h_{min}	h_{max}	q''_{min}	q''_{max}
i)	2	25	97.09	909.09
ii)	50	1,000	1428.57	3125
iii)	25	250	909.09	2631.58
iv)	100	20,000	2000	3322.26
v)	2,500	100,000	3296.75	3331.11

9.3) $V = .5$ m/s $\Delta T = 10°C$



$L_c = .5$ m

Graph Re, Gr, Gr/Re^2 over $10°C \le T_f \le 90°C$

$283.15\text{K} \le T_f \le 363.15$

only non-fixed quantities are β & ν

$\beta = 1/T_f$ air

$\boxed{\text{assume fluid is air}}$ @ 1 atm

temp.	ν_{air} A-4
250	11.44
300	15.89
350	20.92
400	26.41

$$Gr = \frac{g \Delta T L_c^3}{\nu^2 T_f}$$

$$Re = \frac{V L_c}{\nu}$$

interpolation

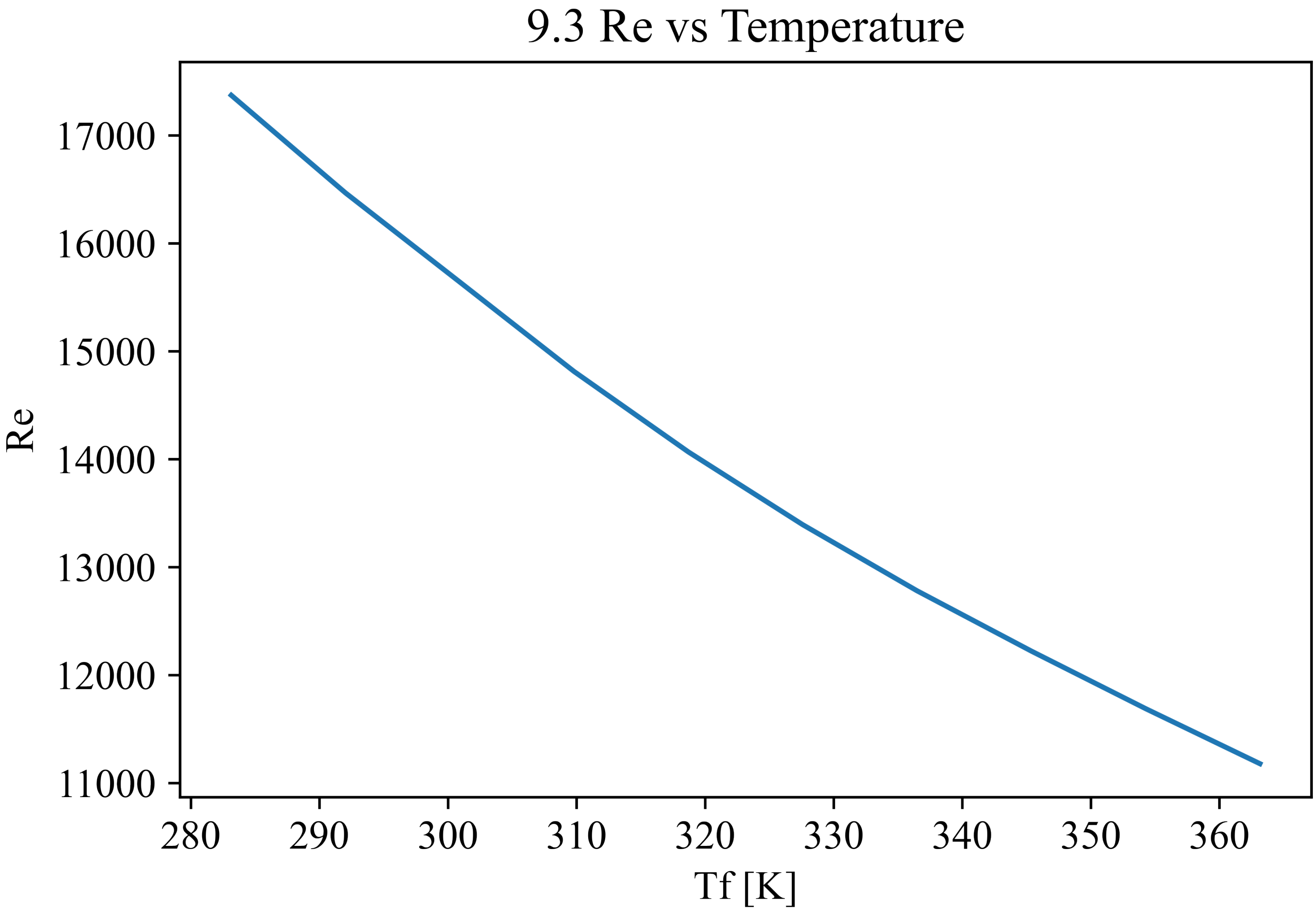
$$\frac{T_f - T_1}{T_2 - T_1} = \frac{\nu_f - \nu_1}{\nu_2 - \nu_1}$$

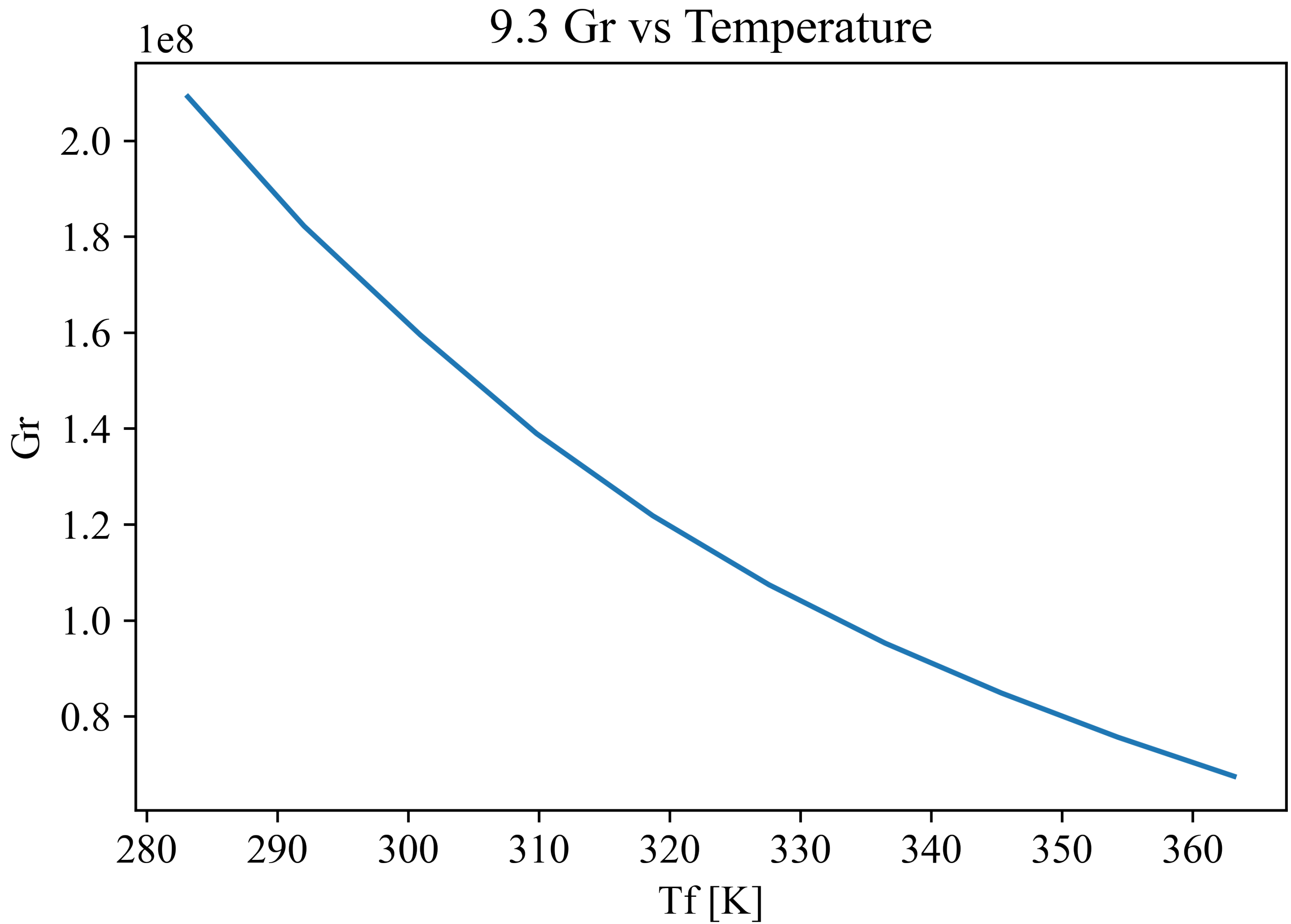
$$\nu_f = \frac{T_f - T_1}{T_2 - T_1} \cdot (\nu_2 - \nu_1) + \nu_1$$

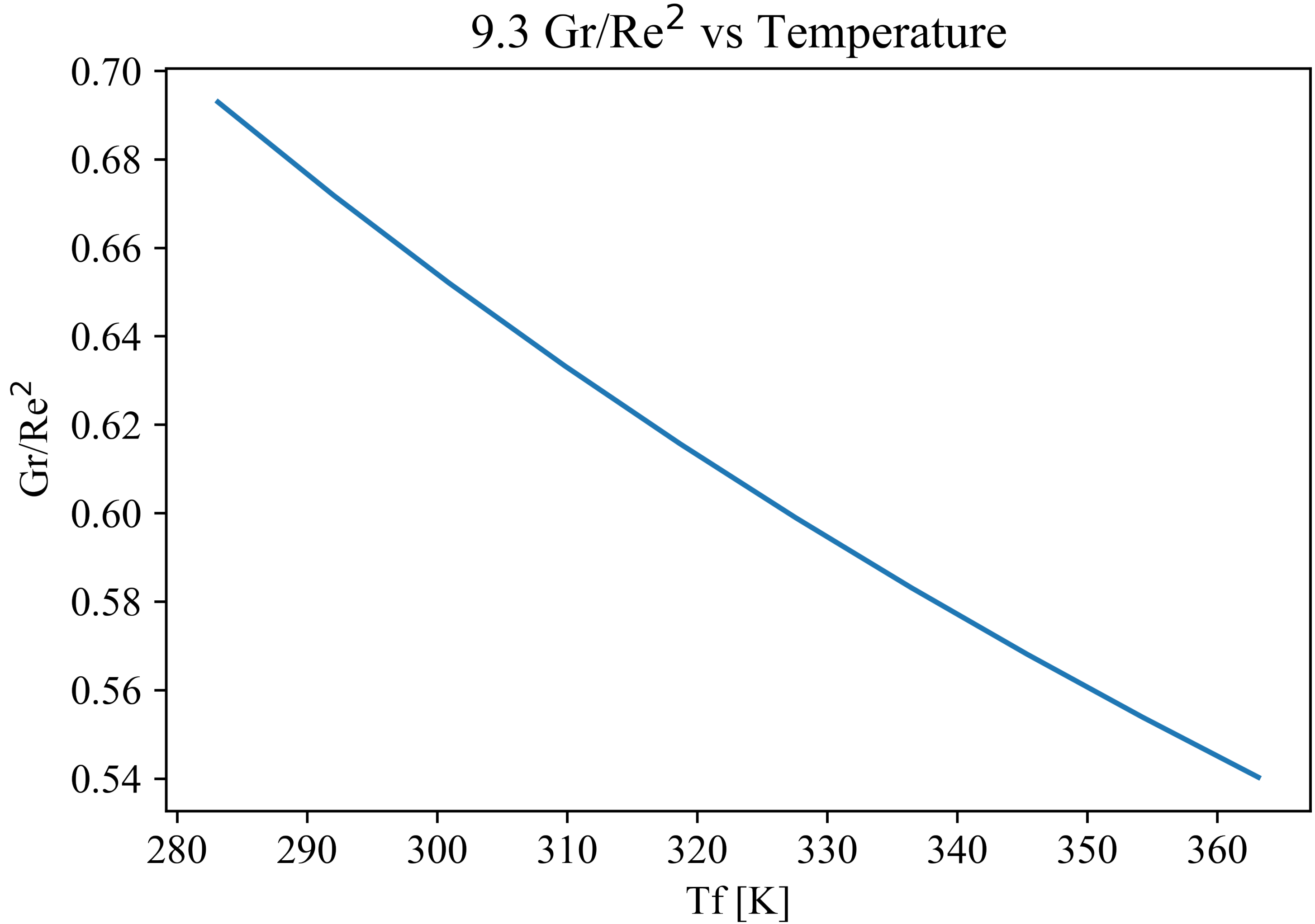
math done in python

```python
#9.1
#Constants
L, k, T1, T2 = 75e-3, 2.5, 200, 100

#h values
h_min = np.array([2,50,25,100,2500])
h_max = np.array([25,1000,250,2e4,1e5])

#q values
def q_func(h):
    return (T1-T2)/(2/h+L/k)
q_min, q_max = q_func(h_min), q_func(h_max)

#Tabulating
table91 = pd.DataFrame(np.array([h_min,h_max,q_min,q_max]))
table91.index = ['h min','h max','q flux min','q flux max']
table91.columns = ['free gas','free liquid','forced gas','forced liquid'
display(HTML(table91.T.to_html()))
```

	h min	h max	q flux min	q flux max
free gas	2.0	25.0	97.087379	909.090909
free liquid	50.0	1000.0	1428.571429	3125.000000
forced gas	25.0	250.0	909.090909	2631.578947
forced liquid	100.0	20000.0	2000.000000	3322.259136
phase change	2500.0	100000.0	3246.753247	3331.112592


9.3 Re vs Temperature
17000
16000
15000
14000
13000
12000
11000
Re
280
290
300
310
320
330
340
350
360
Tf [K]


9.3 Gr vs Temperature
1e8
2.0
1.8
1.6
1.4
1.2
1.0
0.8
Gr
280
290
300
310
320
330
340
350
360
Tf [K]


9.3 Gr/Re^2 vs Temperature
Gr/Re^2
0.70
0.68
0.66
0.64
0.62
0.60
0.58
0.56
0.54
280
290
300
310
320
330
340
350
360
Tf [K]

HW#7

9.4) $L_c = 0.015\,m$, $\Delta T = 10°C$ find Ra for... (constant) $\nu = \frac{\mu}{\rho}$, $\alpha = \frac{k}{\rho c_p}$

$Ra = GrPr = \frac{g\beta\Delta T L_c^3}{\nu^2} \cdot \frac{\nu}{\alpha} = g\Delta T L_c^3 \cdot \frac{\beta}{\nu\alpha}$ need β, ν, α for each fluid

$g\Delta T L_c^3 = (9.81)(10)(0.015)^3 = 3.31e{-4}$

Air (1 atm, 400K) Table A.4

$\beta = 1/T_f = 1/400$, $\nu = 26.41e{-6}$, $\alpha = 38.3e{-6}$

$Ra = g\Delta T L_c^3 \cdot \frac{1}{(400)(26.41e{-6})(38.3e{-6})} = \boxed{818.31}$ air

He (1 atm, 400K) Table A.4

$\beta = 1/T_f = 1/400$, $\nu = 199e{-6}$, $\alpha = 295e{-6}$

$Ra = g\Delta T L_c^3 \cdot \frac{1}{(400)(199e{-6})(295e{-6})} = \boxed{14.10}$ He

Glycerin (285K) Table A.5

$\beta = \frac{1}{2}(.47+.48)e{-3} = 0.475e{-3}$, $\nu = \frac{1}{2}(4200+1460)e{-6} = 2830e{-6}$, $\alpha = \frac{1}{2}(.972+.955)e{-7} = 9.635e{-6}$

$Ra = g\Delta T L_c^3 \cdot \frac{\beta}{\nu\alpha} = \boxed{576.76}$ Glycerin

Water (310K) Table A.6

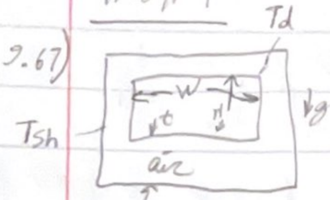
$\beta = 361.9e{-6}$ $\nu = \mu_f v_f = (695e{-6})(1.007e{-3}) = 7.0e{-7}$

$\alpha = k_f v_f / c_{pf} = (628e{-3})(1.007e{-3})/(4.178e{-3}) = 1.51e{-7}$

$Ra = g\Delta T L_c^3 \cdot \frac{\beta}{\nu\alpha} = \boxed{1.13e6}$ H_2O

HW#7

9.67)



$T_d = 40°C$, $T_{sh} = 20°C$, $g = 9.81\ m/s^2$

$W = .8m$, $H = .3m$, $t = 0.06m$

find q'/L

A.4 for air) say $T_{air} = \frac{1}{2}(40+20)°C = 303\ K \approx \underline{300K} = T_{air}$

$\beta = 1/303$, $\nu = 15.89e{-6}$, $\alpha = 22.5e{-6}$, $k = 26.3e{-3}$, $Pr = 0.707$

need $Ra = \dfrac{g\beta\Delta T t^3}{\nu\alpha} = \dfrac{(9.81)(\frac{1}{303})(20)(0.06)^3}{(16.19e{-6})(22.5e{-6})} = 3.84e5$

use 9.50 for
$Nu = 0.22\left(\dfrac{Pr}{0.2+Pr}Ra\right)^{0.28}\left(\dfrac{\overset{H+2t}{H}}{t}\right)^{-1/4} = 0.22\left(\dfrac{0.707}{0.2+0.707}3.85e5\right)^{0.28}\left(\dfrac{.30+.12}{.06}\right)^{-1/4} = 4.62$

$\Rightarrow h_{vert} = \dfrac{Nu\,k}{t} = \dfrac{4.62 \times 26.5e{-3}}{0.06} = 2.041\ W/m^2K$

for top & bot, heating is different. Bot has no convection as heated from top

bot: $Nu = 1 \Rightarrow h_{bot} = k/t = 26.3e{-3}/0.06 = 0.438\ W/m^2K$

top: $Ra > Ra_{crit}$ ∴ Eq. 9.49; $Nu = 0.069\,Ra^{1/3}Pr^{0.074} = 4.89$

$h_{top} = Nu\,k/t = (4.89)(26.3e{-3})/(0.06) = 2.14\ W/m^2 \cdot K$

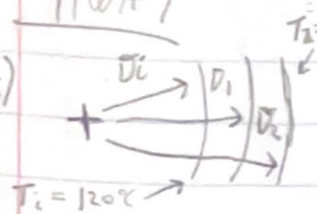
$q' = [2h_{vert}(H+2t) + (h_{bot}+h_{top})(W)]\Delta T$

$= [2(2.041)(.42) + (0.438+2.14)(.8)]\,20$

$$\boxed{q'_{conv} = 75.54\ W/m}$$

HW#7

9.74)



$D_i = 100e{-3}\,m$, $D_1 = 120e{-3}\,m$, $D_2 = 140e{-3}\,m$

$L = 10e{-3}\,m$

A-4) $T = \frac{1}{2}(T_i + T_o) = \frac{1}{2}(120+35)°C = 350K$, $\nu = 20.92e{-6}\,m^2/s$

$k = 0.03\,W/m\cdot K$, $Pr = 0.7$, $\alpha = 29.9$, $\beta = 1/350$

$q' = \frac{T_i - T_2}{R_1 + R_2} = \frac{T_i - T_1}{R_1}$ Eq 9.58) $\frac{q}{L} = q' = \frac{2\pi k_{eff} \Delta T}{\ln(r_o/r_i)}$ Eq 9.59) $k_{eff} = 0.386k\left(\frac{Pr}{0.861 + Pr}\right)^{1/4} Ra_c^{1/4}$

Eq 9.60) $L_c = \frac{2[\ln(r_o/r_i)]^{4/3}}{(r_i^{-3/5} + r_o^{-3/5})^{5/3}}$ w/ $Ra = g\beta\Delta T L_c^3/\alpha\nu$

& $R_1 = \frac{\ln(D_o/D_i)}{2\pi k_{eff}}$ $T_1 = T_i - q' R_1$

solve using iterative python

$\Rightarrow$ a) $q' = 44.9\,W/m < q'_{ideal} = 100\,W/m$

b) $q' = 47.3\,W/m$, expect to $\uparrow$