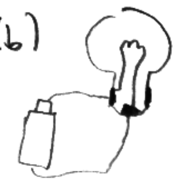
METR 4553 $\boxed{\text{Solutions to Final Exam}}$ May 11, 2017

(1) (a) b

(b)



(c) 1 deg

(d) d

(e) 90°

(f) $X_{now} = \frac{4}{3}$, $\log_2(X_{now}) = .42$, $\Delta T_{now} = 0.6$ C

$$\Delta T_{dbl} = \frac{\Delta T_{now}}{\log_2(X_{now})} \qquad \Delta T_{dbl} = 1.43 \text{ C}$$

(g) $X = \frac{1200}{300} = 4$, $\log_2(X) = 2$, $\Delta T = 1.43\text{C} \times 2 = 2.86$ C

(h) $1 \to \overset{(c)}{4}$ $\quad 2 \to \overset{(d)}{.25}$ $\quad 3 \to \overset{(a)}{200}$ $\quad 4 \to \overset{(b)}{50}$

(i) disequilibrium, T_s is rising.

(j) Approximately 14,000 years ago an ice dam repeatedly broke, unleashing a massive flood.

(k) Northern hemisphere summer insolation was greater, causing stronger monsoon wind and more rainfall.

(l) Methane is a greenhouse gas, causing more warming, more methane release.

② (a) $10^8 \frac{bbl}{d} \cdot \frac{d}{8.6\times10^4 s} = 1160 \frac{bbl}{s}$

(b) $10^8 \frac{bbl}{d} \cdot \frac{365 d}{1 y} \cdot \frac{0.159 m^3}{bbl} \cdot \frac{1 mi^3}{(1610 m)^3} = 1.4 \frac{mi^3}{y}$

(c) $1160 \frac{bbl}{s} \times 159 \frac{l}{bbl} = 0.184\times10^6 \frac{l}{s}$

$0.184\times10^6 \frac{l}{s} \cdot 32 \frac{MJ}{l} = 5.9\times10^{12} W = 5.9 TW$

(d) $5.9\times10^{12} \frac{J}{s} \cdot 3.15\times10^7 \frac{s}{y} \cdot \frac{1 quad}{10^{18} J} = 200 \frac{quad}{y}$

(e) $\frac{5.9\times10^{12}}{7\times10^9} W = 860 W$

③ $A = 1.5\times10^8 ha \cdot \frac{10^4 m^2}{ha} = 1.5\times10^{12} m^2$

(a) $L = \sqrt{A} = 1.2\times10^6 m = 1200 km = 745 mi$

(b) $\frac{1.5\times10^{12} m^2}{3\times10^8} = 5000 m^2$

(c) $\sqrt{5000 m^2} = 71 m$

(d) $1.5\times10^8 ha \cdot 50 \frac{t}{ha\, y} \cdot \frac{100 l}{t} \cdot 22 \frac{MJ}{l} = 1.65\times10^{13} \frac{MJ}{y}$

$= 1.65\times10^{19} \frac{J}{y} = 16 \frac{quad}{y}$, so 16 %

④ $P = 4.8 \dfrac{\text{quad}}{y} = \dfrac{4.8 \times 10^{18}\,J}{3.1 \times 10^7\,s} = 1.55 \times 10^{11}\ W$

(a) $\dfrac{P}{N} = \dfrac{1.55 \times 10^{11}\ W}{3 \times 10^8} = 500\ W = 0.5\ kW$

(b) $0.5\ kW \times 720\,h = 360\ kWh$

$360\ kWh \times .15 \dfrac{\$}{kWh} = \$54$ (per month)

⑤ (a) $\dfrac{30\ K}{3 m^2 K W^{-1}} = 10\ W\,m^{-2} \equiv F$

(b) $A = 200 + 2 \times 10 \times 3 + 2 \times 20 \times 3 = 200 + 60 + 120 = 380\ m^2$

$P = F \cdot A = 3800\ W = 3.8\ kW$

(c) $E = P \cdot 720\,h = 2736\ kWh$

$\text{cost} = 410 \dfrac{\$}{\text{month}}$ $\leftarrow \times\ 0.15 \dfrac{\$}{kWh}$

(d) $4 \dfrac{\$}{GJ} = \dfrac{4\,\$}{1000\,MJ} \cdot \dfrac{3.6\,MJ}{kWh} = 0.014 \dfrac{\$}{kWh}$

(e) $\text{cost} = 2736\ kWh \cdot 0.014 \dfrac{\$}{kWh} = 39 \dfrac{\$}{\text{month}}$

(6)
(a) $2 \frac{\text{gallon}}{\text{hour}} \times 4 \frac{l}{\text{gallon}} = 8 \frac{l}{hr}$

(b) $2000 \frac{l}{ha\,yr} = 0.2 \frac{l}{m^2 yr} \times \frac{1\,yr}{8776\,hr} = 2.2 \times 10^{-5} \frac{l}{m^2 hr}$

(c) $L = 200\ m$

$$L \cdot W \cdot 2.2 \times 10^{-5} \frac{l}{m^2 hr} = 8 \frac{l}{hr}$$

$$W = \frac{8 \frac{l}{hr}}{200\,m \cdot 2.2 \times 10^{-5}\ l\ m^{-2} hr^{-1}} = 1818\ m.$$

(d) $\frac{22 \times 10^6 J}{l} \cdot \frac{0.2\ l}{m^2\ 3 \times 10^7 s} = 0.15\ W m^{-2}$

(7)
(a) $\frac{190 \times 10^6\ MWh}{10^4\ h} = 190 \times 10^2\ MW = 19 \times 10^3\ MW$
$= 19\ GW$

(b) 19 nukes

(c) $\frac{19\ GW}{82\ GW} = 0.23$

(d) Nukes lost in Japan: $200 \frac{TWh}{y}$.

U.S wind production: $190 \times 10^6 \frac{MWh}{y} = 190 \times 10^{12} \frac{TWh}{y}$

Numbers are nearly equal.

(8) (a) $F\uparrow = 0.22 \times 390.8 + 0.78 \times 194.47 = 237.67\ W m^{-2}$

(b) $F\uparrow = 0.22 \times 395.53 + 0.78 \times 197.70 = 241.22\ W m^{-2}$

So $F\uparrow$ increases by $3.55\ W m^{-2} K^{-1}$

(c) $F\uparrow = 0.16 \times 390.8 + 0.84 \times 194.47 = 225.9\ W m^{-2}$

So $F\uparrow$ is decreased by 11.8

(d) Need to increase $F\uparrow$ by 11.8 by increasing T by ΔT:

$$3.55\ W m^{-2} K^{-1} \times \Delta T = 11.8\ W m^{-2}$$

$$\Delta T = \frac{11.8\ W m^{-2}}{3.55\ W m^{-2} K^{-1}} = 3.3\ K$$

(9) (a) $T = \sqrt[4]{\frac{239}{5.67 \times 10^{-8}}}\ K = 255\ K = -18C = 0F$

(b) $T = \sqrt[4]{\frac{396}{5.67 \times 10^{-8}}} = 289.1\ K$

(c) $T = \sqrt[4]{\frac{397}{5.67 \times 10^{-8}}} = 289.29\ K$

(d) $337 + 161 - 81 - 17 = 400\ W m^{-2}$

(e) $A_E = 5 \times 10^{14}\ m^2$

$A_{ocean} = 0.7 \times 5 \times 10^{14}\ m^2 = 3.5 \times 10^{14}\ m^2$

$P = 10^{22}\ \frac{J}{y}$

$$\frac{P}{A_{ocean}} = \frac{10^{22}\ J\ y^{-1}}{3.5 \times 10^{14}\ m^2} \cdot \frac{1y}{3.2 \times 10^{7}\ s}$$

$$= \frac{10^{22}\ J}{11.2 \times 10^{21}\ s\ m^2} = 0.89\ \frac{J}{s m^2} = 0.89\ W m^{-2}$$

10 (a) Need 800 more GtC, so 200 years.

$$\left(200\,y \cdot 4\,\frac{GtC}{y}\right) = 800\ GtC$$

(b) $\frac{4}{800} = \frac{x}{400}$ $\quad x = 2\ ppm\ y^{-1}$

(c) $\frac{9}{800} = \frac{x}{400}$ $\quad x = 4.5\ ppm\ y^{-1}$

(d) $$\frac{800\ \overset{\leftarrow 10^9}{G}\overset{10^3}{t}C}{5\times10^{14}\ m^2} = 1.6\ \frac{kg}{m^2}$$

(e) $$\frac{44 \leftarrow CO_2}{12 \nwarrow C} \times 1.6\ \frac{kg}{m^2} = 5.9\ \frac{kg}{m^2}$$

(g) If the biomass carbon was recently taken out of the atmosphere, it is being returned. The net flux is zero.

(f) $$63\ GtC \times \frac{1.16\ toe}{1\ tC} = 73\ Gtoe$$

$$73\times10^9\ toe \times 42\times10^9\ \frac{J}{toe} = 3000\times10^{18}\ J$$

$$= 3000\ quad$$

30 × the energy used by USA.