Problem Set 12.1: Waves and Photons

1. The comment that light can be transmitted as an electromagnetic wave refers to the face that light can be modelled by coupled transverse waves, one a magnetic field and the other an electrical field, at right angles to each other, that move forward by creating each from the other at the speed of light.

2. a) The term coherent is used to describe light sources of the same frequency, and that have a constant phase difference (ie they are in phase.).

   b) No – because they are producing more than one frequency of EM radiation. Coherent light must be monochromatic, as even if the light sources produced the same range of frequencies, there is no reason why both sources will produce the same frequency at the same time.

3. According to the formula $E = hf$ the energy of a photon is reliant not on the velocity of the photon, but on its frequency. Different colours of light correspond to photons of different frequencies, and therefore, according to $E = hf$, different energies.

4. $E = hf$
   $E = (6.63\times10^{-34})(3.85\times10^{14})$
   $E = 2.55\times10^{-19}$ J

5. $E = hf$
   $1.00\times10^{-17} = (6.63\times10^{-34})f$
   $f = 1.58\times10^{16}$ Hz

   This corresponds to the Ultraviolet region of the EM spectrum

6. a) $E = hf$
   $E = (6.63\times10^{-34})(1.30\times10^{6})$
   $E = 8.62\times10^{-28}$ J

   b) $c = \lambda f$
   $\lambda = \frac{3.00\times10^{8}}{1.30\times10^{6}}$
   $\lambda = 2.31\times10^{2}$ m

   c) $E = \frac{1}{2}\, m\, v^2$
   $8.62\times10^{-28} = \frac{1}{2}(9.11\times10^{-31})v^2$
   $v = 4.35\times10^{1}$ ms^{-1}

7. a) $c = \lambda f$
   $\lambda = \frac{3.00\times10^{8}}{2650\times10^{6}}$
   $\lambda = 1.13\times10^{-1}$m

   b) $E = hf$
   $E = (6.63\times10^{-34})(2650\times10^{6})$
   $E = 1.76\times10^{-24}$ J

c) Energy after 2.5 mins:

$E_{tot} = P.t$

$E_{tot} = 1100 \times 2.5 \times 60$

$E_{tot} = 165000$ J

$n_{photon} = \frac{E_{tot}}{E_{photon}}$

$n_{photon} = \frac{165000}{1.76 \times 10^{-24}}$

$n_{photon} = 9.38 \times 10^{27}$ photons

8. a) UV

b) $E = hf$

$E = \frac{hc}{\lambda}$

$E = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{905 \times 10^{-9}}$

$E = 2.20 \times 10^{-19}$ J

c) $E_{pulse} = P.t$

$E = 34(150 \times 10^{-9})$

$E = 5.1 \times 10^{-6}$ J

$n_{photons} = \frac{E_{pulse}}{E_{photon}}$

$n_{photon} = \frac{5.1 \times 10^{-6}}{2.20 \times 10^{-19}}$

$n_{photon} = 2.32 \times 10^{13}$ photons

9. Antennas need to be mounted in an orientation which corresponds to the method of polarisation the waves they're receiving have been subject to. Horizontal antennas are placed to receive TV signals, as the TV signals are horizontally polarised themselves.

10. a) $c = \lambda f$

$\lambda = \frac{3.00 \times 10^{8}}{1.52 \times 10^{9}}$

$\lambda = 1.97 \times 10^{-1}$ m

b) $E = hf$

$E = (6.63 \times 10^{-34})(1.52 \times 10^{9})$

$E = 1.01 \times 10^{-24}$ J

c) $n_{photons\ in\ 1\ second} = \frac{E_{energy\ released\ in\ 1\ second}}{E_{photon}}$

$n_{photons\ in\ 1\ second} = \frac{5.00}{1.01 \times 10^{-24}}$

$n_{photons\ in\ 1\ second} = 4.95 \times 10^{24}$ photons in 1 second

d) Assuming time elapsed starts with the first pulse:
250 pulses in 1 second.

$E_{single\ pulse} = \frac{E_{1\ second}}{E\ pulses\ in\ 1\ second}$
$E_{single\ pulse} = \frac{5.00}{250}$
$E_{single\ pulse} = 2.00\times10^{-2}$J

11. $c = \lambda f$
$f = \frac{3.00\times10^{8}}{435\times10^{-9}}$
$f = 6.90\times10^{14}$Hz

$E = hf$
$E = (6.63\times10^{-34})(6.90\times10^{14})$
$E = 4.57\times10^{-19}$J

$P = E_{photon} \cdot n_{photons\ in\ 1\ second}$
$P = 4.57\times10^{-19}. 3.25\times10^{18}$
$P = 1.49$W

$W = P.t$
$W = 1.49\times1.2\times10^{-3}$
$W = 1.78\times10^{-3}$J

12. a) $E = hf$
$E = \frac{hc}{\lambda}$
$E = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{694\times10^{-9}}$
$E = 2.87\times10^{-19}$ J

b) $I = \frac{P}{A}$
$I = \frac{1.00}{10\times10^{-6}}$
$I = 100000$ W.m^{-2}

c) Laser is 100x brighter.

13. $E = hf$
$E = \frac{hc}{\lambda}$
$E = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{6.00\times10^{-7}}$
$E = 3.32\times10^{-19}$ J

$n_{photons\ in\ 1\ second} = \frac{E_{energy\ released\ in\ 1\ second}}{E_{photon}}$
$n_{photons\ in\ 1\ second} = \frac{1.70\times10^{-8}}{3.32\times10^{-19}}$
$n_{photons\ in\ 1\ second} = 5.13\times10^{10}$ photons in 1 second

14. a) $c = \lambda f$

$\lambda = \frac{3.00\times10^{8}}{720\times10^{3}}$

$\lambda = 4.17\times10^{2}\text{m}$

b) Assuming the full power is used for the day:

$E = P.t$

$E = 50\times10^{3}\times60\times60\times24$

$E = 4.32\times10^{9}\text{J}$

15. a) $E = hf$

$f = \frac{E}{h}$

$f = \frac{2.00\times10^{-24}}{6.63\times10^{-34}}$

$f = 3.02\times10^{9}$ Hz

b) $c = \lambda f$

$\lambda = \frac{3.00\times10^{8}}{3.02\times10^{9}}$

$\lambda = 9.95\times10^{-2}\text{m}$

c)

	Compared to VL
E	Smaller
f	Lower
λ	Greater

16. a) Green light has a higher frequency than the IR beam, which means it is less likely to interact with the molecules on the way through the water.

b) High intensity means the beam consists of many photons. It needs a high intensity because photons may scatter due to collisions with molecules in the water. The more photons, the more photons that will successfully be reflected back.

c) Wavelength = $.75\times532 = 399$ nm

d) Frequency doesn't change between different media

$f = \frac{c}{\lambda}$

$f = \frac{3\times10^{8}}{532\times10^{-9}}$

$f = 5.64\times10^{14}$ Hz

e) Speed of light in water is roughly 75% of the speed of light in air.

$speed = \frac{distance}{time\ from\ bottom\ of\ ocean\ to\ top}$

$0.75\times3\times10^{8} = \frac{distance}{\frac{1}{2}(3.8\times10^{-6})}$

$distance = 427.5$ m

17. a) Incandescent globes only emit a small proportion of energy supplied as visible light. A large proportion of the energy supplied is radiated as heat; EM radiation in the Infrared range.

b) Blackbody curve should have its peak in the UV part of the spectrum.

c) $c = \lambda f$

$\lambda = \frac{3.00\times10^{8}}{5.28\times10^{16}}$

$\lambda = 5.68\times10^{-9}$ m

d) $E = hf$

$E = (6.63\times10^{-34})(5.28\times10^{16})$

$E = 3.50\times10^{-17}$ J

$E = 2.19\times10^{2}$ eV

e) $n_{photons\ in\ 1\ second} = \frac{E_{energy\ released\ in\ 1\ second}}{E_{photon}}$

$n_{photons\ in\ 1\ second} = \frac{75.0}{3.50\times10^{-17}}$

$n_{photons\ in\ 1\ second} = 2.14\times10^{18}$ photons in 1 second

f) It would be hard to determine the number of photons from experimental measure, as the photons are not travelling in a beam towards a detector like in a laser, but radially. This is impractical to detect due to the fact they can travel in any direction.