keep it simple science

KEEP IT SIMPLE SCIENCE

Physics Module 7

The Nature of Light

WORKSHEETS

Worksheet 1 EM Spectrum

Student Name.....................................

Guided Notes. (Make your own summary)

1.
a) List the 7 "types" of EM radiation in order of increasing frequency.

b) Although we commonly recognise these as 7 different radiations, they are really all the same. Explain this statement.

2.
Outline Maxwell's contribution to our understanding of EMR.

3.
Describe the <u>general method</u> by which all EM waves are produced.

4.
Explain the difference between an emission spectrum & an absorption spectrum in terms of:
a) how each is formed.

4. (cont)
b) how each appears (what it looks like)

5.
How can the spectrum of a star be used to find:
a) its surface temperature?

b) its chemical composition?

c) its movement towards or away from Earth?

d) its rotational motion?

e) its density?

keep it simple science

Worksheet 2 Test-Style Questions

Answer in the spaces provided.
(on reverse, if insufficient room)

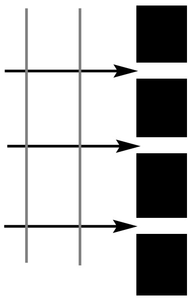
Student Name......................................

1.
Briefly explain how and why the spectrum associated with a particular element contains discrete "lines", either absorption or emission lines.

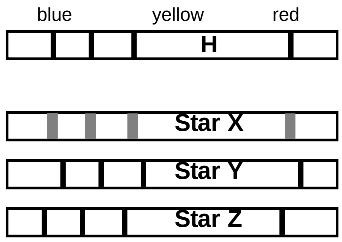
2.
a) What is diffraction?

b) The diagram shows a breakwall with parallel water waves approaching. There are 3 boat channels through the wall. Complete the diagram showing the pattern of the waves which go through the boat channels.

Water waves striking a breakwall with 3 boat channels



3.
Diagram "H" shows the absorption spectrum of hydrogen, while "X", "Y" and "Z" are part of the absorption spectra from 3 different stars.



State how each spectrum differs from "H" and what that reveals about the <u>motion</u> of the stars X, Y and Z.

Worksheet 3 Young's Double-Slit Experiment Practice Problems.

Student Name......................................

1.
A red low-power laser with λ = 634nm was beamed at a double-slit grating. An interference pattern appeared on a screen 2.50 m from the grating. The distance from central spot to the next bright spot was 22.5cm.

What is the spacing between the slits in the grating?

2. The red laser (in Q1) is replaced by a blue laser with a shorter wavelength. All else is the same.

Show mathematically whether the interference pattern it produces will place the bright spots closer or further apart.

3.
Given that the blue laser in Q2 has a wavelength of 445 nm, calculate the "spot-spacing" for the same slit grating and screen distance as in Q1.

4.
A green laser beam produces spots which are 0.334m apart (central to m=1) when a grating is used with slits 3,000 nm apart and a screen 1.90m away. What is the wavelength of the laser light?

keep it simple science

Worksheet 4 Malus's Law Practice Problems

Student Name....................................

1.
A beam of light has been passed through a polarising filter and its irradiance is measured to be 250 Wm^{-2}. What is the irradiance value of the beam after passing through an "analyser" filter which is aligned at an angle (to the polariser) of:

a) 45^o?

b) 75^o?

c) 20^o?

2.
At what angle must a polariser & analyser be aligned for the irradiance of a beam of light to be reduced to exactly half of its I_{max} value?

3.
A beam of sunlight which has passed through a polariser and analyser is found to have a final irradiance value of 188 Wm^{-2}. The filters are aligned at 60^o. What was the irradiance value just before it hit the analyser filter?

4.
Outline the significance of Young's Experiment (1801) & Malus's Law (1809) on the understanding of the nature of light.

Worksheet 5 Wien's Law Practice Problems

Student Name....................................

1.
What would be the "peak" wavelength on a "radiation curve", of a "black body" at a temperature of:

a) 9,000 K ?

b) 5,800 K ?

c) 40,000 K ?

d) 12,000 K?

2.
What would be the temperature (K) of a "black body" which has a "peak" wavelength of

a) 1.5×10^{-7} m? (ultra-violet range)

b) 8.7×10^{-7} m? (infra-red range)

c) 4.2×10^{-7} m? (visible, blue)

d) 6.5×10^{-7} m? (visible, orange)

keep it simple science

Worksheet 6 Planck's Quantum Theory
Practice Problems

Student Name....................................

1.
A light wave has a wavelength of 4.25×10^{-7}m.
a) What is its frequency?

b) How much energy is carried by one photon?

2.
Compare the amount of quantum energy carried by a photon of
i) infra-red (heat) radiation ($\lambda = 5.45 \times 10^{-6}$m) and
ii) UV radiation ($\lambda = 5.45 \times 10^{-9}$m)

3.
A photon of radiation is carrying 8.75×10^{-14}J of energy. Calculate:
a) its frequency

b) its wavelength

c) By comparing your answers to other data in this worksheet, suggest whether or not this radiation is visible light.

Worksheet 7 How Quantum Theory Developed

Fill in the blanks

Student Name....................................

In 1887, Heinrich Hertz discovered a)...................... waves. His experiment involved high voltage from an b)............................... coil which produced c)..................... across a gap. The sparking produced radio waves which he detected with a d)... in which a small gap also sparked. He was able to show that the new radiations showed typical wave properties such as e)........................... and .... Hertz was also able to measure the f)............................ of the waves, and show it was equal to the speed of g)............................. He also produced evidence of the h)....................................... Effect, but failed to investigate it further.

Meanwhile, other researchers had studied the way energy is emitted from hot objects. The "i)................................ Radiation" curves showed a shape that could not be explained by the accepted theories. In 1900, j)............................. proposed the "k)............................ Theory" to account for the problem. The basic idea of his theory is that the energy of light (or other EMR) is "l).........................." the same way that matter is. The minimum quantity of matter is one m)........................, and fractions cannot occur. Plank proposed that the energy of EMR is the same, and that the amount of energy carried by a wave is related to the n).......................... of the wave.

The "Photoelectric Effect" occurs when o)......................... is absorbed at a metal surface. The energy is transferred to an p)............................ which may then be q)............................ from the surface. Experiments with this effect were producing results that could not be explained.

In 1905, Einstein used Plank's r).............................. Theory to explain all the difficulties. His idea was:
- **Light is a wave, but the energy is concentrated in "bundles" called "s)..............................."**
- **Each bundle carries an amount of energy, as described by t)...................................... theory.**
- **When a photon interacts with matter, it can either transfer u).......................... of its energy, or v)............................. of it, but cannot transfer w)..**

This idea allows light to have its "wave properties" such as x)............................., ... and ...., but to also sometimes show y)............................-like properties when it transfers energy.
Based on this theory, Einstein made certain mathematical z).............................. regarding the aa)................................. Effect. These were confirmed in 1916. This confirmed Plank's ab)............................ Theory, and explained all the "problems" with ac)............................ .... radiation & the ad)................................. Effect.

keep it simple science

Worksheet 8 Quantum Theory
Test-Style Questions

Student Name....................................

Multiple Choice

1. Which of the following best describes the outcome of Hertz's famous experiments of 1887?
A. His discoveries led to the Quantum Theory of light.
B. He showed that light gives interference patterns.
C. He confirmed Maxwell's EM theory.
D. He got a more accurate value for the speed of light.

2. According to "Quantum Theory", if you compared the energy of 2 photons of light and found that one had more energy than the other, then the one with more energy must have:
A. more mass.
B. longer wavelength.
C. higher frequency.
D. a higher velocity.

3. The "Photoelectric Effect" involves:
A. emission of electrons that have absorbed energy from a photon.
B. emission of a photon of light that has absorbed the excess energy from a falling electron.
C. using photographic film to get an image of x-ray interference patterns.
D. using an electrical induction coil to cause sparks in a separate receiving coil or antenna.

**4. According to Einstein, light often behaves like a wave, but sometimes acts like a particle.
A phenomenon in which the particle nature of a photon is noticeable, is:**
A. interference of photons after diffraction.
B. refraction of light by a glass lens.
C. photoelectric effect occurring on a metal surface.
D. polarisation of light by sunglasses.

Longer Response Questions

Answer on reverse if insufficient space.

5.
Two different photons of light have wavelengths of 5.00×10^{-7}m (photon P) and 2.40×10^{-8}m (photon Q).
Qualitatively (no calculation required) compare P & Q's:
a) speed

b) frequency

c) energy

Explain your answers in each case.

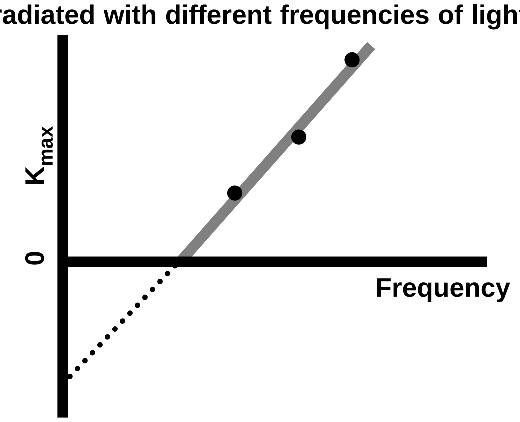
6.
For an electron to escape from the surface of a particular metal, it needs to absorb a minimum of 6.75×10^{-19}J of energy. Calculate the
a) frequency

b) wavelength
of a photon with just enough energy to cause this.

7.
The "work function" of the metal lithium is 4.6×10^{-19} J. If irradiated with light of frequency 9.5×10^{14} Hz, what is:
a) the max.KE of the photoelectrons ejected?

b) their velocity?

8.
The graph shows the maximum KE of photoelectrons escaping a metal surface when irradiated with different frequencies of light.



What is the significance of:
a) the graph's gradient?

b) the intercept on the y-axis? (by extrapolation)

c) the intercept on the x-axis?

keep it simple science®

Worksheet 9 Development of Relativity Theory

Fill in the blanks

Student Name......................................

The theory of the "aether" was invented to explain a)... because it was thought that all waves needed a b)............................ to travel through. The aether was invisible and c)..............................., and was present throughout the d)...................................

The American scientists e).............................. & .... attempted to detect the aether by experiment. Their apparatus used 2 f)................................., travelling at right angles. When brought together by mirrors, the beams produced an g)... pattern. The idea was that the pattern should change when the apparatus was h)................................., because one beam should be travelling with the "aether wind" and the other i).............................. it. This "aether wind" would be caused by j)...................................... .... through space. The result was that k)...

An "l)............................ Frame of Reference" is one which is not m)...................................... Within such a place, all measurements and experiments will give the n)............... .... This idea is known as the "Principle of o)..".

Albert Einstein applied this principle to the Michelson-Morley result. He concluded that all observers will always measure the speed of light as being p)................................... For this to happen, then q)............................... and .... must be relative. This means that the measurements of length and time as seen by r).................. .... will be different.

Relativity Theory predicts that length will s)......................... while time will t)............................ Also, mass will u)..................................., thereby making it impossible to actually v)... Relativity also predicts that mass can be converted into w)................................... and vice-versa.

Although it defies common sense, many aspects of Relativity have been confirmed by x).. For example, synchronised clocks have been found to disagree if one of them is y)... .... The conversion of mass into energy has been observed (many times) during z)........................... reactions.

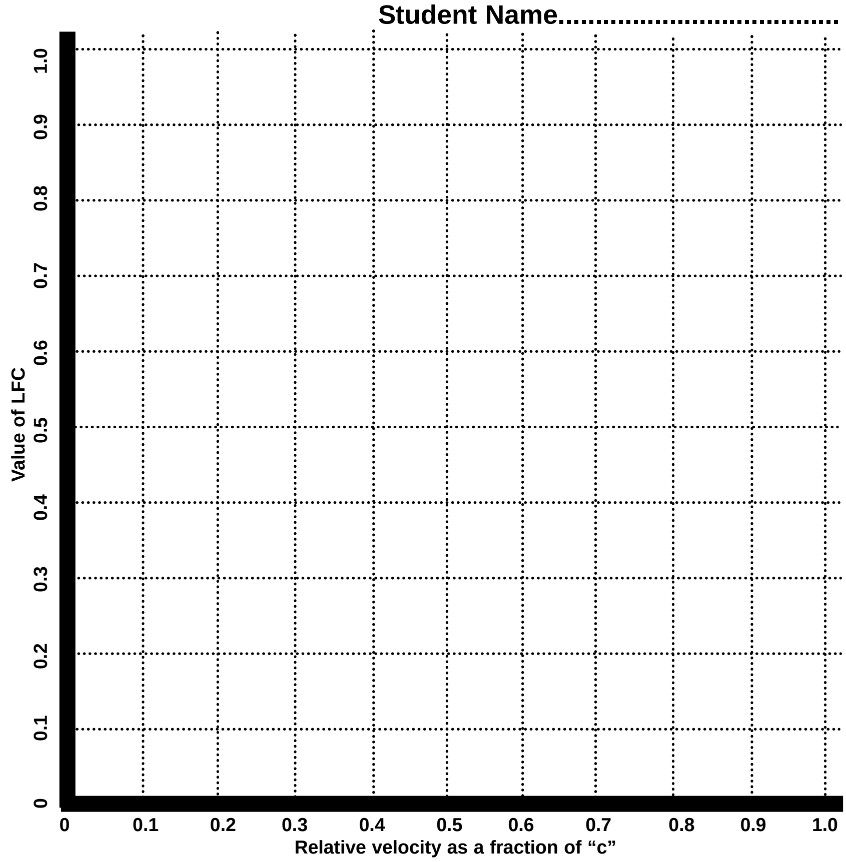
Worksheet 10 Lorentz-FitzGerald Contraction (LFC) Calculations & Graphing

Student Name......................................

1. Complete the list of values, then plot the points and construct a line (curve) of best fit.
(you may also find these values useful in other calculation problems)

Relative velocity	Value of LFC
0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1.0	

2.
What happens to the relativistic measurements of length, time & mass as velocity approaches "c"?



keep it simple science®

Worksheet 11 Special Relativity Practice Problems

Student Name......................................

1.
A spacecraft is travelling at 90% of the speed of light relative to an observer on Earth. On board is a fluorescent light tube which is 1.25m long and is switched on for 1 hour ship-time.

a) How long is the fluoro-tube as measured by the Earth observer?

b) The Earth observer measures the time for which the light was on. What time does he/she measure?

2.
A sub-atomic particle has a "rest mass" of 5.95×10^{-29} kg. The particle was accelerated by a particle accelerator up to a velocity of 0.99c. (99% "c")

a) What relativistic momentum will the particle now have, if measured by the scientists in the laboratory?

b) What relativistic momentum will it have if accelerated up to 0.9999c? (99.99% of "c")

3.
In a nuclear reactor, over a period of time, a total of 2.35kg of "mass deficit" occurs. This mass has "disappeared" during the nuclear reactions. Calculate the amount of energy this has released.

4.
According to the "Big Bang" Theory, in the first moments of the Universe there was nothing but energy. Later, matter formed by conversion from the energy.

Calculate how much energy was needed to produce enough matter to form the Earth (mass= 5.97×10^{24}kg).

5.
The "twins paradox" is a hypothetical situation involving relativity. A pair of identical twins are 20 years old when one of them volunteers as an astronaut for a deep-space mission on a new high-speed spaceship. The other twin stays on Earth and monitors her sister's journey.

The astronaut twin travels away from Earth and back, at a speed of 0.99c for 10 years measured onboard the spacecraft.

a) How much time passes on Earth?

b) How old is each twin at the end of the journey?

6.
We finish with a true story from the early days of space flight.

Some American astronauts spent about a month in orbit at a speed of about 25,000 $kmhr^{-1}$. As a joke, they calculated the relativistic distance they had travelled in space and found it was a few metres more than the official distance covered, as measured from Earth. They then submitted a salary claim for the extra travelling. The claim was for a tiny fraction of a cent.

In the spirit of the joke, NASA granted their claim, then "docked" their pay by the same amount for not working the full time of flight. Their relativistic time in space was found to be a few milliseconds less than the official Earth time of flight.

But that's OK. They were happy in the knowledge that they are a little bit younger than they would have been otherwise.

keep it simple science

Answer Section

Worksheet 1

1.
a) radio waves, microwaves, infra-red, visible light, ultra-violet, x-rays, gamma radiation.

b) All these "types" are the same form of wave, but have different wavelengths & frequencies. They form a continum with no distinct demarcation between "types".

2.
Prior to Maxwell no-one had any idea exactly what light is. His mathematical description of a wave of oscillating electric & magnetic fields established light as an EM wave and predicted the existence of an entire "family" of EMR.

3.
Any electric charge which accelerates or oscillates will emit EMR at a corresponding frequency.

4.
a) Emission spectra form when electrons in an atom drop to lower orbits. As they do so, they emit light at precise frequencies.
Absorption spectra form when a full "rainbow" of light waves pass through an atom and light of specific frequencies is absorbed. The energy is absorbed by electrons which jump to higher orbit levels.

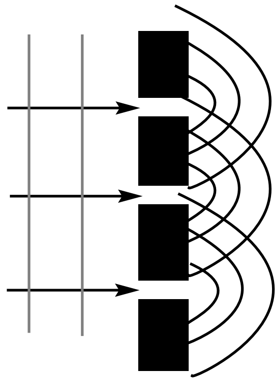
b) Emission spectra appear as narrow bright lines of light on a dark background. (through a spectroscope)
Absorption spectra appear as a bright rainbow of colours with dark lines, where certain frequencies have been absorbed.

5.
a) From the "peak" intensity wavelength of its EMR emission graph.
b) By matching the "Fraunhofer Lines" in its spectrum against the known spectral lines of the elements.
c) By any "Doppler Shift" in the spectral lines, to shorter (approaching) or longer (receding) wavelengths.
d) By the "smearing" or widening of spectral lines due to doppler shifts in the light from opposite edges of the rotating star.
e) High density also "smears" the spectral lines, but in a different way to the rotational widening.

Worksheet 2

1.
The spectral lines correspond to light of particular frequency which has either been emitted or absorbed by the electrons as they jump from one energy level to another. To jump higher, they must absorb energy, while to drop lower they must emit energy. The frequency of the light is related to the energy difference.

2.
a) When waves pass through a small gap in a barrier, the gap acts like a point source of waves, which spread out in a semi-circular pattern.
b)



3.
<u>Spectrum X</u>: lines are blurred. This shows the star is rotating, resulting in both red and blue doppler shifts from its edges. This blurs the lines.
<u>Spectrum Y</u>: lines are red-shifted, showing that this star is moving away from Earth.
<u>Spectrum Z</u>: lines are blue-shifted, showing that this star is moving towards Earth.

Worksheet 3

1.

$\tan\theta = \Delta y / L = 0.225 / 2.50 = 0.090$

$\therefore \theta = 5.14^o$

$d.\sin\theta = m.\lambda$, so $d = m.\lambda / \sin\theta$
$= 1x634 / \sin 5.14$
$= 7{,}080$ nm

2.
$d.\sin\theta = m.\lambda$, so $\sin\theta = m.\lambda / d$

Therefore, if the wavelength is shorter, the angle becomes smaller. This will cause the bright spots to be closer together.

3.
$d.\sin\theta = m.\lambda$, so $\sin\theta = m.\lambda / d = 1x445 / 7{,}080$
$= 0.470$
$\therefore \theta = 3.60^o$
$\Delta y = L.\tan\theta = 2.50 \times \tan 3.60 = 0.157$ m (15.7 cm)

4.

$\tan\theta = \Delta y / L = 0.334 / 1.90 = 0.176$

$\therefore \theta = 9.97^o$

Then, $d.\sin\theta = m.\lambda$

so $\lambda = d.\sin\theta / m = 3{,}000 \times \sin 9.97 / 1$
$= 519$ nm (5.19×10^{-7} m)

keep it simple science

Answer Section

Worksheet 4

1.

a) $I = I_{max}.\cos^2\theta$ = 250 x $\cos^2$ 45 = 125 Wm^{-2}

b) $I = I_{max}.\cos^2\theta$ = 250 x $\cos^2$ 75 = 16.7 Wm^{-2}

c) $I = I_{max}.\cos^2\theta$ = 250 x $\cos^2$ 20 = 221 Wm^{-2}

2. $I = I_{max}.\cos^2\theta$ so $\cos^2\theta = I / I_{max}$
= 0.50 / 1 = 0.50

$\therefore \cos\theta = \sqrt{0.50}$ = 0.707 so $\theta = 45^o$

3. $I = I_{max}.\cos^2\theta$ so $I_{max} = I / \cos^2\theta$
= 188 / $\cos^2$ 60
= 752 Wm^{-2}

4.
Prior to Young & Malus there was still controversy about the nature of light. Huygens' wave theory had a lot of evidence in its favour, but Newton's particle theory had some evidence, plus the greater influence of Newton's reputation.

The work of Young & Malus (both theories mathematically developed and in agreement with experiment) were based on light being a wave. The success of these "Laws" to explain diffraction, interference & polarisation phenomena was powerful evidence for light being accepted as a transverse wave.

Worksheet 5

1.

a) λ_{max} = b / T = 2.898x10^{-3} / 9,000 = 3.22 x 10^{-7} m.

b) λ_{max} = b / T = 2.898x10^{-3} / 5,800 = 5.00 x 10^{-7} m.

c) λ_{max} = b / T = 2.898x10^{-3} / 40,000 = 7.25 x 10^{-8} m.

d) λ_{max} = b / T = 2.898x10^{-3} / 12,000 = 2.42 x 10^{-7} m.

2.

a) λ_{max} = b / T so T = b / λ_{max}
= 2.898x10^{-3} / 1.5x10^{-7}
= 19,300 K

b) λ_{max} = b / T so T = b / λ_{max}
= 2.898x10^{-3} / 8.7x10^{-7}
= 3,330 K

c) λ_{max} = b / T so T = b / λ_{max}
= 2.898x10^{-3} / 4.2x10^{-7}
= 6,900 K

d) λ_{max} = b / T so T = b / λ_{max}
= 2.898x10^{-3} / 6.5x10^{-7}
= 4,460 K

Worksheet 6

1.

a) $c = \lambda.f$, so $f = c/\lambda$
= 3.00x10^8 / 4.25x10^{-7}
= 7.06x10^{14}Hz.

b) E = h.f = 6.63x10^{-34} x 7.06x10^{14} = 4.68 x 10^{-19} J.

2. i) <u>infra-red</u> ii) <u>UV</u>

$c = \lambda.f$,

so $f = c/\lambda$	$f = c/\lambda$
= 3.00x10^8/5.45x10^{-6}	= 3.00x10^8/5.45x10^{-9}
= 5.50x10^{13} Hz	= 5.50x10^{16} Hz
E = h.f	E = h.f
= 6.63x10^{-34}x5.5x10^{13}	= 6.63x10^{-34}x5.5x10^{16}
= 3.65x10^{-20} J.	= 3.65x10^{-17} J.

Comparison:
UV photon carries 1,000 times more energy because frequency is 1,000 X higher

3.

a) E = h.f, so f = E/h = 8.75x10^{-14}/6.63x10^{-34}
= 1.32x10^{20} Hz.

b) $c = \lambda.f$, so $\lambda = c/f$ = 3.00x10^8/1.23x10^{20}
= 2.44x10^{-12}m.

c) This is extremely high energy, high frequency, short wavelength EMR more like x-ray or gamma radiation rather than visible light.

Worksheet 7

a) radio	b) induction
c) sparks	d) wire loop antenna
e) reflection & diffraction	f) velocity
g) light	h) Photoelectric
i) Black Body	j) Max Planck
k) Quantum	l) quantised
m) atom	n) frequency
o) light energy	
p) electron	q) emitted
r) Quantum	s) photons
t) quantum	u) all
v) none	w) part of its energy.
x) reflection, refraction & diffraction (plus others)	
y) particle	z) predictions
aa) Photoelectric	ab) Quantum
ac) Black Body	ad) Photoelectric

keep it simple science

Answer Section

Worksheet 8

1. C 2. C 3. A 4. C

5.

a) both travel at the same velocity (= $3\text{x}10^8\text{ms}^{-1}$ in vacuum) because ALL EMR waves travel at this "speed of light".

b) Photon Q has a shorter wavelength, and therefore must have higher frequency.

c) Photon Q carries more energy, because quantum energy is proportional to frequency.

6.

a) $E = h.f$, so $f = E/h = 6.75\text{x}10^{-19} / 6.63\text{x}10^{-34}$
$= 1.02\text{x}10^{15}$ Hz.

b) $c = \lambda.f$, so $\lambda = c/f = 3.00\text{x}10^8 / 1.02\text{x}10^{15}$
$= 2.94\text{x}10^{-7}$ m.

7.

a) $E_{max} = h.f - \phi = 6.626\text{x}10^{-34} \text{ x } 9.5\text{x}10^{14} - 4.6\text{x}10^{-19}$
$= 1.69 \text{ x } 10^{-19}$ J.

b) This is KE, so $E_{max} = 0.5.m.v^2$
so $v^2 = 2.E / m = 2\text{x } 1.69\text{x}10^{-19} / 9.109\text{x}10^{-31}$
$\therefore v = 6.10 \text{ x } 10^5 \text{ ms}^{-1}$.

8.

a) It is equal to the value of Planck's constant.

b) Its magnitude is equal to the value of the "work function" of metal.

c) It is the "threshold frequency" (f_o) below which no photoelectrons will be emitted.

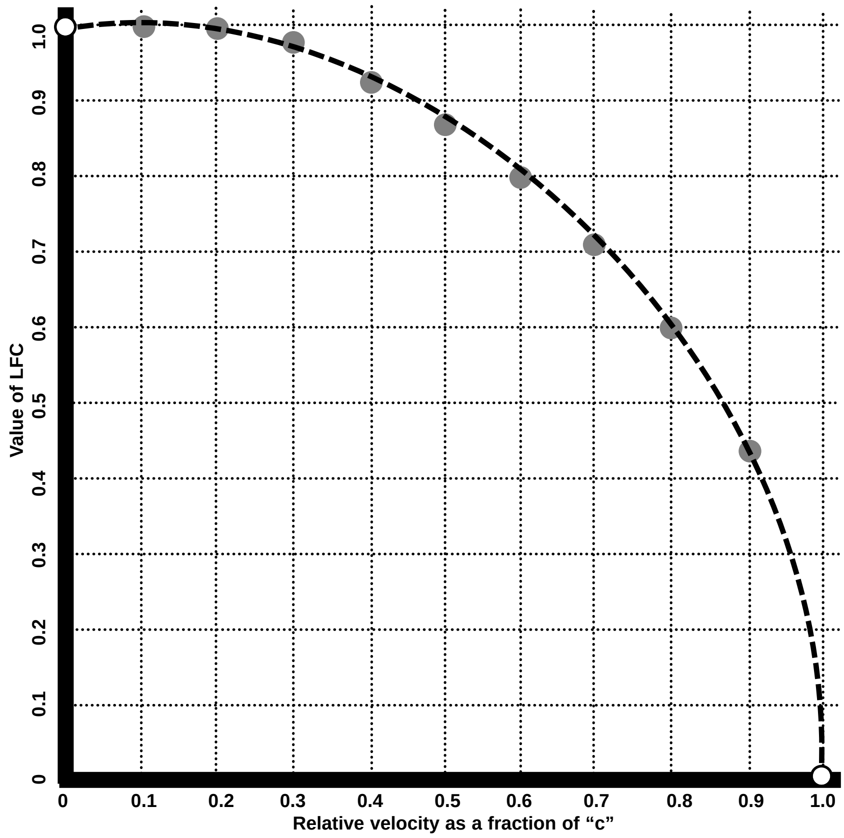
Worksheet 9

a) transmission of light in vacuum
b) medium
c) massless / weightless
d) Universe
e) Michelson & Morley
f) beams of light
g) interference
h) rotated 90 degrees
i) across
j) the Earth's motion
k) no change to the interference pattern, so no aether wind detected.
l) Inertial
m) accelerating
n) same results
o) Relativity
p) the same
q) length & time
r) an observer travelling at a different relative velocity
s) shorten
t) lengthen / slow down
u) increase
v) accelerate to the speed of light
w) energy
x) observation/experiment
y) transported at high speed
z) nuclear

Worksheet 10

1.

Relative velocity	Value of LFC
0	1.0
0.1	0.99
0.2	0.98
0.3	0.95
0.4	0.92
0.5	0.87
0.6	0.80
0.7	0.71
0.8	0.60
0.9	0.44
1.0	0



2.

Length (in the direction of the relative motion) becomes shorter. (contraction)

Time runs slower.
ie each second becomes longer (dilation).

Mass increases. (dilation)

keep it simple science

Answer Section

Worksheet 11

Using the abbreviation "LFC" = $\sqrt{1 - \frac{v^2}{c^2}}$

1.
a) At 0.90 c, LFC = 0.44 (from worksheet 10 table)

$L = L_0 \times LFC = 1.25 \times 0.44 = 0.55$m.
b) $t = t_0 / LFC = 1 / 0.44 = 2.27$ hours.

2.
a) At 0.99c, LFC = 0.141
$\rho = m_0 v / LFC = 5.95\times10^{-29} \times 0.99 \times 3\times10^{8} / 0.141$
$= 1.25\times10^{-19}$ kgm^{-1}.

b) At 0.9999c, LFC = $\sqrt{(1 - (0.9999^2/1^2))} = 0.01414$
$\rho = m_0 v / LFC$
$= 5.95\times10^{-29} \times 0.9999 \times 3\times10^{8} / 0.01414$
$= 1.26\times10^{-18}$ kgm^{-1}.

(Relativistic momentum has increased by 10 times, while velocity increased by only about 10%)

3.
$E = mc^2 = 2.35\times(3.00\times10^{8})^2 = 2.12\times10^{17}$J.

4.
$E = mc^2 = 5.97\times10^{24}\times(3.00\times10^{8})^2 = 5.37\times10^{41}$ J.

5.
At 0.99c, LFC = 0.141

a) $t = t_0 / LFC = 10 / 0.141 = 70.9$ years.
This means almost 71 years have elapsed on Earth!

b) Therefore, the astronaut's age is 30 years, but her earthbound twin is now 91 years old.
(Is this really a practical way to stay young?)