M15/4/PHYSI/HP3/ENG/TZ1/XX/M

Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2015

Physics

Higher level

Paper 3

18 pages

International Baccalaureate®
Baccalauréat International
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1. Follow the markscheme provided, award only whole marks and mark only in **RED**.

2. Make sure that the question you are about to mark is highlighted in the mark panel on the right-hand side of the screen.

3. Where a mark is awarded, a tick/check (✓) **must** be placed in the text at the **precise point** where it becomes clear that the candidate deserves the mark. **One tick to be shown for each mark awarded.**

4. Sometimes, careful consideration is required to decide whether or not to award a mark. In these cases use RM™ Assessor annotations to support your decision. You are encouraged to write comments where it helps clarity, especially for re-marking purposes. Use a text box for these additional comments. It should be remembered that the script may be returned to the candidate.

5. Personal codes/notations are unacceptable.

6. Where an answer to a part question is worth no marks but the candidate has attempted the part question, use the "ZERO" annotation to award zero marks. Where a candidate has not attempted the part question, use the "SEEN" annotation to show you have looked at the question. RM™ Assessor will apply "NR" once you click complete.

7. If a candidate has attempted more than the required number of questions within a paper or section of a paper, mark all the answers. RM™ Assessor will only award the highest mark or marks in line with the rubric.

8. Ensure that you have viewed **every** page including any additional sheets. Please ensure that you stamp "SEEN" on any additional pages that are blank or where the candidate has crossed out his/her work.

9. There is no need to stamp an annotation when a candidate has not chosen an option. RM™ Assessor will apply "NR" once you click complete.

10. Mark positively. Give candidates credit for what they have achieved and for what they have got correct, rather than penalizing them for what they have got wrong. However, a mark should not be awarded where there is contradiction within an answer. Make a comment to this effect using a text box or the "CON" stamp.

Subject Details: Physics HL Paper 3 Markscheme

Mark Allocation

Candidates are required to answer questions from **TWO** of the Options **[2 × 30 marks]**.
Maximum total = **[60 marks]**.

1. A markscheme often has more marking points than the total allows. This is intentional.

2. Each marking point has a separate line and the end is shown by means of a semicolon (;).

3. An alternative answer or wording is indicated in the markscheme by a slash (/). Either wording can be accepted.

4. Words in brackets ( ) in the markscheme are not necessary to gain the mark.

5. Words that are underlined are essential for the mark.

6. The order of marking points does not have to be as in the markscheme, unless stated otherwise.

7. If the candidate's answer has the same "meaning" or can be clearly interpreted as being of equivalent significance, detail and validity as that in the markscheme then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by ***OWTTE*** (or words to that effect).

8. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

9. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking indicate this by adding **ECF** (error carried forward) on the script.

10. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the markscheme.

Option E — Astrophysics

1. U N S J; **[1]**

2. (a) (i) $T = \dfrac{0.0029}{\lambda}$;

3080/3090 (K); *(more than 1 SD must be shown)* **[2]**

(ii) temperature too low for white dwarf;

not luminous enough for red giant; **[2]**

(b) (i) $L = 4\pi d^2 b$;

$\dfrac{d_B}{d_S}\left(= \sqrt{\dfrac{L_B}{L_S}\dfrac{b_S}{b_B}}\right) = \sqrt{\dfrac{3.8\times10^{-3}}{2.5\times10^{-14}}}$;

3.9×10^5 AU; **[3]**

Ñ (ii) conversion of AU to 1.89 pc;

(ii) conversion of AU to 1.89 pc;

0.53 (arc-seconds); **[2]**

(iii) measure position of star;

with respect to fixed background;

with six months between readings;

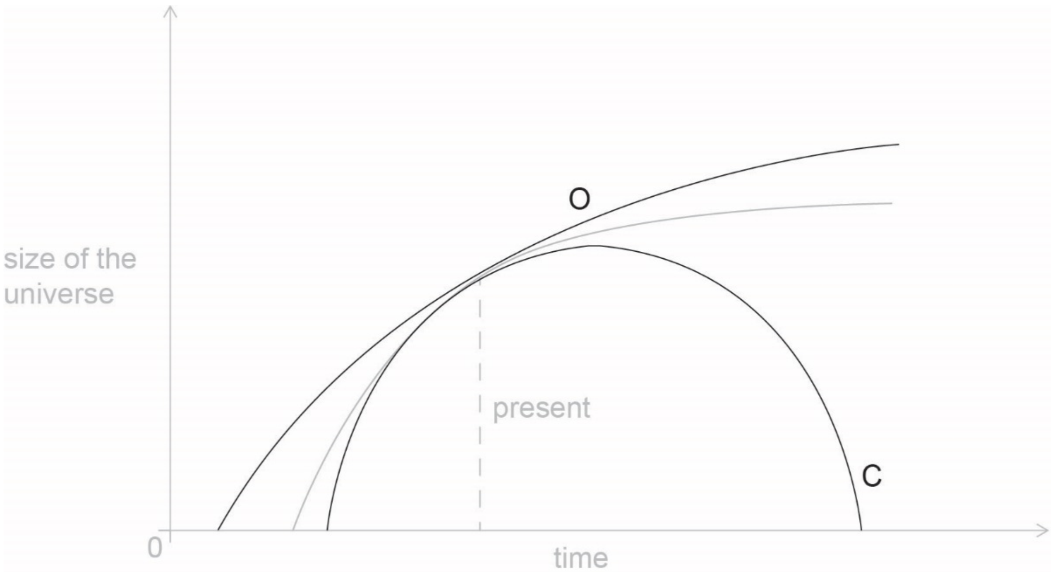
parallax angle is half the total angle / *OWTTE*; **[3 max]**

May be shown in a diagram.

3. (a) after present, open universe curve drawn above flat curve **and** closed universe curve drawn under flat curve; *(both needed for mark)*

all meet at "present time"; **[2]**

Ignore curves before present time.



(b) if density less than critical density/too low the universe will expand for ever;

if greater than critical density the universe contracts;

after an initial expansion; **[3]**

*If critical density not mentioned award **[1 max]**.*

4. (a) luminosity $= 30^{3.5} = 148\,000$ (times the luminosity of the Sun) ***or***

mass $= (1.5 \times 10^{5})^{\frac{1}{3.5}} = 30$ (times the mass of the Sun);
(this is close to the quoted luminosity/mass and) so X must be on the main sequence; **[2]**

(b) (i) red (super)giant goes supernova with core remaining; **[1]**

(ii) Oppenheimer–Volkoff/mass of remnant will determine final fate;
(to give) neutron star/black hole; **[2]**

5. (a) (fabric of the) universe is expanding;
so the wavelength of the light increases;
during the time it has travelled from emitter to detector; **[3]**

(b) (i) correct substitution into $H_0 = \frac{v}{d}$;

2.7×10^{-18} (s^{-1}); **[2]**

(ii) $\frac{1}{2.7 \times 10^{-18}} = 3.8 \times 10^{17}$ (s) / 3.7×10^{17}; **[1]**

Allow ECF from (b)(i).

(iii) universe has always had a constant rate of expansion; **[1]**

Option F — Communications

6. (a) the signal wave is/contains the information;
the carrier wave is modulated by the signal wave; **[2]**

(b) (i) difference between the highest and lowest frequency / range of frequencies in a signal; **[1]**

(ii) 1600 (kHz); **[1]**

(iii) difference in frequencies seen;
60 (kHz); **[2]**

(c) worse signal-to-noise ratio / worse quality / more power required for transmission; **[1]**

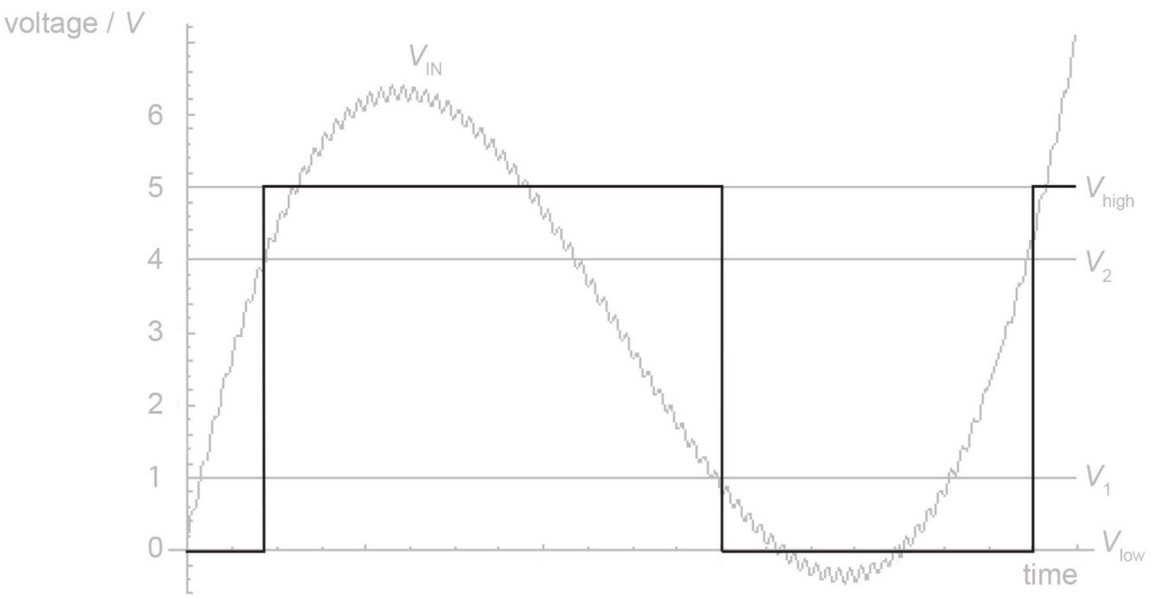
7. (a) (i) a distortion in the shape of the pulse as it travels through the fibre / *OWTTE*;
different components (frequencies or modes) of the pulse take different times to get across the fibre/get separated in time/are spread out; **[1 max]**

(ii) mention of <u>modal and material</u> dispersion;
(material) dispersion is caused by variation of propagation velocity/refractive index with wavelength;
(modal) dispersion is when rays of light of the same wavelength follow different paths/travel different distances along the fibre; **[3]**

(b) (i) any unwanted signal / *OWTTE*; **[1]**
Accept "a distortion in the shape of the pulse/signal".

(ii) reduction/removal of noise;
by returning pulse to its original shape; **[2]**

(iii) square wave pulse;
between 0 V and 5 V;
verticals intercepting at 4 V; *(judge by eye)*
vertical intercepting at 1 V; *(judge by eye)* **[4]**
eg:



8. (a) a small area/region;
allocated a specific frequency/range of frequencies;
contains a base station; **[2 max]**

(b) manufacture of a great number of phones leads to depletion of natural sources/production of greenhouse gases/problems with disposal;
any other reasonable issue *eg* electromagnetic smog / mobile transmission towers are considered ugly by many / *etc*; **[2]**

9. (a) polar-orbiting satellite closer to Earth's surface / lower orbit;
so lower power signals required;
so time delay between transmission and reception less; *(do **not** accept faster speed of transmission)*
covers whole of Earth's surface during several orbits; **[2 max]**

(b) (i) time-division multiplexing;
signal divided into chunks;
chunks transmitted sequentially;
chunks recombined in sequence at base station;
by using dead times between bursts of data / by assigning time slots to each signal; **[4 max]**
Accept marking points in the form of a clearly labelled diagram.

(ii) interval between samples $\frac{1}{25\,\text{kHz}} = 40\,\mu\text{s}$;
$\frac{40}{9.0} = 4.4$ so maximum number of signals is 4; **[2]**

Option G — Electromagnetic waves

10. (a) need a (lasing) material/gas with a metastable state;
metastable state has (unusually) long mean lifetime;
which allows a population inversion;
population inversion means greater number of excited atoms than non-excited atoms;
photon stimulates all excited atoms to de-excite (to lower level) at the same time;
(stimulating) photon has energy/phase similar to difference between levels; **[4 max]**

(b) (i) *with the first-order spectrum for beam A:*
read-off $\theta = 18^\circ$ for $n = 1$;

$$d = \frac{530\times 10^{-9}}{\sin 18^\circ} = 1.7\times 10^{-6}\text{ (m)};$$

$$\text{lines per millimetre} = \frac{1}{1.7\times 10^{-6}}\times 10^{-3} = 583\ (\sim 600);$$ **[3]**

or

with the second-order spectrum:
read-off $\theta = 39^\circ$ for $n = 2$;

$$d = \frac{2\times 530\times 10^{-9}}{\sin 39^\circ}(= 1.7\times 10^{-6}\text{(m)});$$

$$\text{lines per millimetre} = \frac{1}{1.7\times 10^{-6}}\times 10^{-3} = 583\ (\sim 600);$$

(ii) *with the first-order spectrum for beam B:*
read-off $\theta = 24^\circ$ for $n = 1$;

$$\lambda = \frac{1.7\times 10^{-6}\times \sin 24^\circ}{1} = 690\text{ (nm)};$$ **[2]**

or

with the second-order spectrum:
read off $\theta = 54^\circ$ for $n = 2$;

$$\lambda = \frac{1.7\times 10^{-6}\times \sin 54^\circ}{2} = 690\text{ (nm)};$$

(iii) $\frac{3\times 690\times 10^{-9}}{1.7\times 10^{-6}} = 1.2$;

$\sin\theta = 1.2^\circ$ has no solutions (hence third-order peak does not exist); **[2]**

Allow alternative method using $\sin 90^\circ$.

11. (a) $\left(\frac{1}{0.05}=\right)20$; **[1]**

(b) (i) attempted substitution into thin lens equation; *(allow incorrect signs)*

$v=\frac{2\times 5}{2-5}=(-)3.3$;

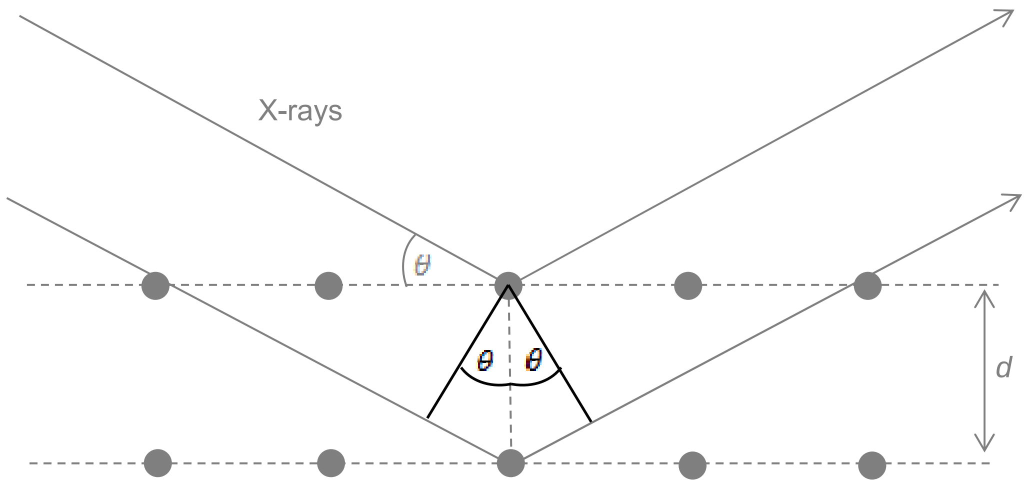
$m\left(=-\frac{v}{u}\right)=\frac{3.3}{2}=1.7$; **[3]**

(ii) virtual because *v* is negative;
erect/upright because virtual/*m* is positive;
enlarged/magnified because *m* is greater than 1; **[2 max]**
Do not allow correct properties without an explanation.

(c) different colours/wavelengths/frequencies have different refractive indices/speed of light (in glass);
(image with colour distortions due to the) different focal points (of said colours/wavelengths/frequencies); **[2]**

(d) use of a chromatic doublet / use a combination of lenses; **[1]**

12. (a) (i) appropriate lines as shown below; **[1]**
Lines must be perpendicular to the X-rays (judge by eye) or marked as θ.



(ii) path difference $=2d\sin\theta$;
constructive interference when $2d\sin\theta=\lambda$; **[2]**
*Award **[0]** for bald answer from the data booklet of* $2d\sin\theta=n\lambda$.

(b) $\lambda_{\text{min}}=\frac{hc}{eV}=\frac{6.63\times10^{-34}\times3.0\times10^{8}}{1.6\times10^{-19}\times15000}$;

$=8.3\times10^{-11}$ (m); **[2]**

13. (a) light reflects from the top surface of the oil and the top surface of the water;
mention of interference/superposition;
path difference exists between both reflected rays;
different wavelengths interfere constructively for different positions/angles (hence colours appear/shift); **[3 max]**

(b) $\lambda\left(=t\dfrac{2n}{m}\right)=250\times10^{-9}\dfrac{2\times1.4}{1}$;
$\lambda=700$ (nm); **[2]**

Option H — Relativity

14. (a) (i) theory suggests that no object can travel faster than light;
the 1.7*c* is not the speed of a physical object;
so is not in violation of the theory; **[2 max]**

(ii) recognition that *v* is negative relative to u_x;
use of $\frac{0.85c+0.85c}{1+\frac{(0.85c)^2}{c^2}}$;
$(0.9869c \approx)\ 0.99c$; **[3]**
Accept first marking point implied in the second marking point.

(b) (i) $\gamma = 1.89$;
interval on Earth $= \gamma \times$ interval on spaceship;
(interval on Earth 1.90×8 years $=$)15 years; **[3]**
*Award **[3]** for a bald correct answer.*

(ii) time interval measured by observer on Earth is not proper because the time interval between the two events is not measured at same place/not the shortest time; **[1]**

(iii) observer on Earth thinks spaceship has travelled for 15 years;
so distance is $0.85c \times 15 = 12.8 \approx 13\,\text{ly}$; **[2]**
*Award **[2]** for a bald correct answer.*

or

the spaceship observer observes the distance moved by the Earth $= 0.85c \times 8.0\,\text{yr}$;
proper distance $= 1.90 \times 0.85c \times 8.0\,\text{yr} = 12.9 \approx 13\,\text{ly}$;
*Award **[2]** for a bald correct answer.*

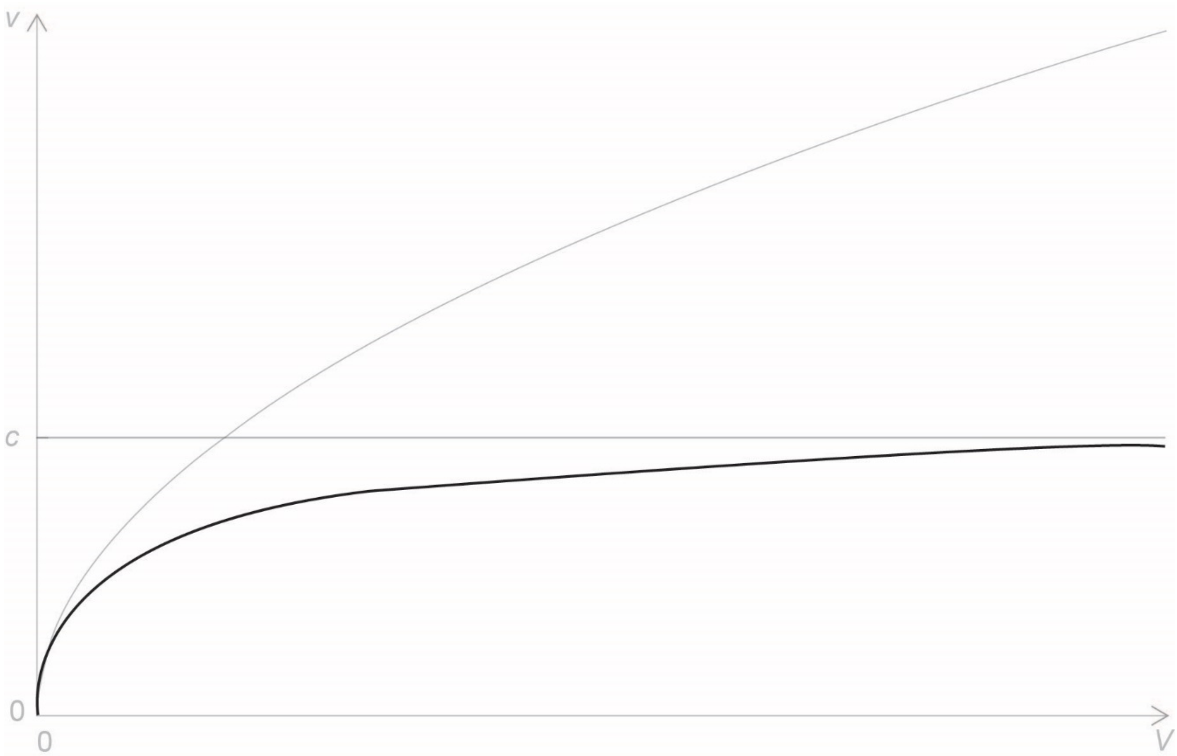
(iv) Earth is at a distance of $4 \times 0.85c = 3.4\,\text{ly}$ when signal is emitted;
signal reaches Earth in time T where $c\text{T} + 3.4 = 0.85c\text{T}$;
$\text{T} = 22.7 \approx 23$ years; **[3]**

15. (a) $E = \gamma mc^2 = 5mc^2$ ***or*** $\gamma = 5$;

so $\frac{v^2}{c^2} = 1 - 0.04$;

$v = 0.98c$; **[3]**

(b) close to Newton for small *v* and below Newton for large *V*;
asymptotic to *c*; **[2]**



16. (a) $\left(R = \frac{2GM}{c^2} =\right) \frac{2 \times 6.7 \times 10^{-11} \times 5.0 \times 10^{30}}{9 \times 10^{16}}$;

$= 7.4 \times 10^3$ (m); **[2]**

(b) closest approach much larger than *R*;
so Newtonian mechanics will apply;
spacetime will not be significantly warped; **[2 max]**

(c) theory predicts that warping of spacetime will affect light;
the massive star is warping spacetime;
causing the light to bend around it; **[3]**
*Award **[2 max]** to an answer that addresses the last two marking points.*
Accept answer to the last two marking points in a form of labelled diagram.

17. special theory predicts that the moving clock runs more slowly than the Earth clock;
time dilation occurs / aircraft clock is accelerated compared to the Earth clock;
general theory predicts that moving clock will run more quickly than Earth clock;
because of the increase in gravitational potential above the surface / increased distance from a massive body speeds up time;
mention of principle of equivalence relating to last point; **[4 max]**

Option I — Medical physics

18. (a) intensity level in decibels $= 10\lg\frac{I}{1\times10^{-12}}$ (where I is the measured intensity); **[1]**

(b) (i) A: hearing loss that is constant with frequency (compared to C);
B: hearing loss that increases with frequency; **[2]**
Do not allow comparisons between A and B.

(ii) read-off 35 dB above I_0;
$35 = 10\lg\frac{I}{1\times10^{-12}}$;
3.2×10^{-9} (W m^{-2}); **[3]**

19. (a) use of piezoelectric crystal / quartz;
crystal changes shape/vibrates when an alternating electric field is applied to it;
crystal dimensions are cut to achieve resonance at required frequency; **[2 max]**

(b) (acoustic impedance of air =) 330 × 1.3 = (= 430 ($\text{kg m}^{-2}\,\text{s}^{-1}$));
(acoustic impedance of skin =) 1500 × 1000 = ($=1.5\times10^{6}$ ($\text{kg m}^{-2}\,\text{s}^{-1}$));
$\frac{I_R}{I_0}\approx 1/0.999$;
little/no transmission (because the reflected intensity is approximately equal to the incident intensity);
gel (has similar impedance to skin and so) is required as it excludes air from the interface (so transmission occurs); **[5]**
Accept first two marking points if implied in the third marking point.

(c) A-scan is a "graph" of returned intensity against time but B-scan is a 2-D image of section through patient;
A-scan: ultrasound probe is fixed in position;
B-scan: operator moves ultrasound generator and computer records echo returns; **[3]**

20. (a) $\frac{I_b}{I_f}=\frac{e^{-\mu_b x}}{e^{-\mu_f x}}$;
$= e^{-0.0150\times165}$;
0.0842; **[3]**
*Award **[3]** for a bald correct answer.*

(b) fluorescent emitters are placed each side of the photographic plate;
X-rays cause emission of (visible) light from the fluorescent material that causes (additional) plate exposure;
better contrast because many X-rays pass through plate without interaction / photographic plate is more sensitive to visible light than to X-rays; **[3]**

21. (a) absorbed dose $= \dfrac{0.27 \times 10^{-3}}{5} (= 54\ \mu\text{J})$;
total energy absorbed $(= 54 \times 80) = 4.3\ (\text{mJ})$; **[2]**

(b) increase distance;
reduce exposure time; **[2]**

(c) differential effect mentioned / malignant cells are more susceptible to radiation than normal cells;
(radiation beam is directed at malignant cells) patient/source moved during exposure;
to minimize effect on surrounding normal tissue;
radiation sources implanted close to/in malignant tissue;
to maximize absorption by tissue and energy release to it; **[4 max]**

Option J — Particle physics

22. (a) (i) *W*/intermediate vector boson **and** weak; *(both needed for mark)* **[1]**

(ii) *d* in neutron changes to *u* (in proton); **[1]**

(b) (i) $m = 125 \times 10^{9} \times \dfrac{1.6 \times 10^{-19}}{9 \times 10^{16}} (= 2.2 \times 10^{-25})(\text{kg})$;

$R = \left(\dfrac{h}{4\pi mc} =\right) \dfrac{6.63 \times 10^{-34}}{4\pi \times 2.2 \times 10^{-25} \times 3 \times 10^{8}}$;

$= 7.9 \times 10^{-19}$ (m); **[3]**

(ii) $17\,\text{MeV} = 2.7 \times 10^{-12}$ (J);

$\Delta t > \dfrac{h}{4\pi \times 2.7 \times 10^{-12}}$;

$= 1.9 \times 10^{-23}$ (s); **[3]**

23. (a) charged particles move in (semi) circular paths inside each dee;
the potential between the dees gives rise to an electric field;
as they move between dees they gain energy from the field and accelerate / they accelerate;
when particle reaches the gap (half a circle later) the potential is reversed to re-accelerate; **[4]**

(b) kinetic energy of protons required $= 1000 - 938\,\text{MeV} = 62\,\text{MeV}$;

$62\,\text{MeV} = 9.9 \times 10^{-12}$ (J);

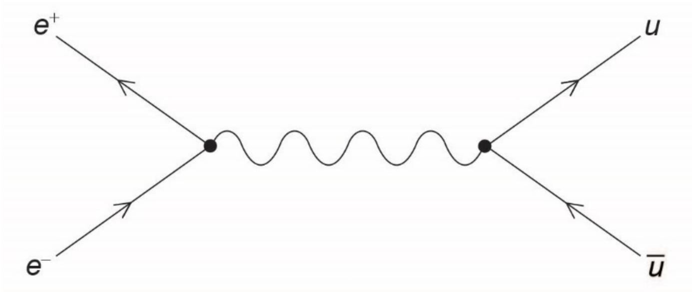
$v = \sqrt{\dfrac{2KE}{m}} = 1.1 \times 10^{8}$ (m s^{-1});

$f = \dfrac{v}{2\pi r} = 35$ (MHz); **[4]**

If 1000 MeV used instead of 62 MeV then:
*Award **[2 max]** if v is greater than speed of light and no comment that this is implausible.*
*Award **[3 max]** if candidate shows v greater than speed of light but comments appropriately.*

(c) frequency of applied potentials vary to allow for increase in (relativistic) mass;
many small individual magnets to allow greater radius (and greater energy); **[2]**

24. (a) particles correctly labelled and interaction correctly shown;
arrow directions correct; **[2]**



(b) strong (colour) interaction increases with separation requiring high energy;
high energy allows creation of hadrons/quarks;
confinement requires the formation of two quarks, not one; **[2 max]**

(c) involves weak interaction;
intermediate particle/Z^0 is uncharged; **[2]**

25. (a) $u\bar{s}$; **[1]**

(b) (i) baryon/lepton number / colour; **[1]**

(ii) strangeness; **[1]**

26. (a) particle with no internal structure/not made of smaller constituents; **[1]**

(b) strings exist in multi-dimensional universe;
elementary particles are described as vibrational modes of the string;
(these are analogous to) harmonic standing waves on vibrating string; **[2 max]**