7 Read the passage below and answer the questions that follow.

Light-emitting diodes – an innovation in lighting

Over recent years there has been a revolution in lighting. Incandescent (filament) lamps were first replaced with compact fluorescent lamps (CFLs). These are now being replaced by light-emitting diodes (LEDs), which are a type of semiconductor diode. LEDs can be found everywhere from car headlights and festival lights to television screens.

When operating in a circuit there is a potential difference (p.d.) V across a diode. A variety of LEDs are now available, each emitting a different wavelength of light and each requiring a different p.d. The p.d. V is related to the frequency f of emitted light by the following equation:

$$V = kf^n$$

where k and n are constants.

An LED is destroyed when the p.d. across it is too high. A protective resistor is connected in series with the LED to prevent this. The normal operating current through an LED is 20 mA.

LEDs are becoming very popular as they are much more efficient than incandescent lamps and produce the same illumination at a considerably lower input electrical power. The luminous flux of a light source is measured in lumens. This is more useful when comparing the power output from a light source than its electrical power input. For example, a 60 W incandescent lamp produces an illumination of 840 lumens whereas an LED lamp produces an illumination of 800 lumens for a 10 W power consumption.

The availability of LEDs emitting white light means that they are now very commonly used for all types of torch. A typical power supply for a torch is rated at 730 mAh. The small current required by an LED means that the power supply will not need to be replaced or recharged as often as for a torch using an incandescent lamp.

Another key difference between the two light sources is their structure. An incandescent lamp consists of a thin wire filament encased in a glass envelope containing an inert gas at low pressure. An LED consists of a semiconductor junction encased in resin or plastic.

Data relating the frequency f of the light photons emitted by an LED and the p.d. V across the LED are given for seven LEDs in Table 7.1.

Table 7.1

V/V	$f/10^{14}$ Hz	lg (V/V)	lg (f/Hz)
1.2	3.94	0.079	14.595
1.8	4.65	0.255	14.667
2.0	4.89	0.301	14.689
2.2	5.08	0.342	14.706
2.4	5.36	0.380	14.729
3.6	6.41	0.556	14.807
4.0	6.67	0.602	14.824

(a) Use Table 7.1 to suggest qualitatively the relationship between the p.d. V and the frequency f of the emitted light.

.....

.....[1]

(b) The variation of lg(f/Hz) with lg (V/V) is shown in Fig. 7.1.

(i) Plot the point for $f = 5.08 \times 10^{14}$ Hz on Fig. 7.1. [1]

(ii) Complete Fig. 7.1 by drawing the line of best fit. [1]

(iii) Determine the value of n from your line.

n = ... [2]

(c) **(i)** Use Fig. 7.1 to find the p.d. across an LED emitting photons of wavelength 520 nm.

p.d. = ... V [3]

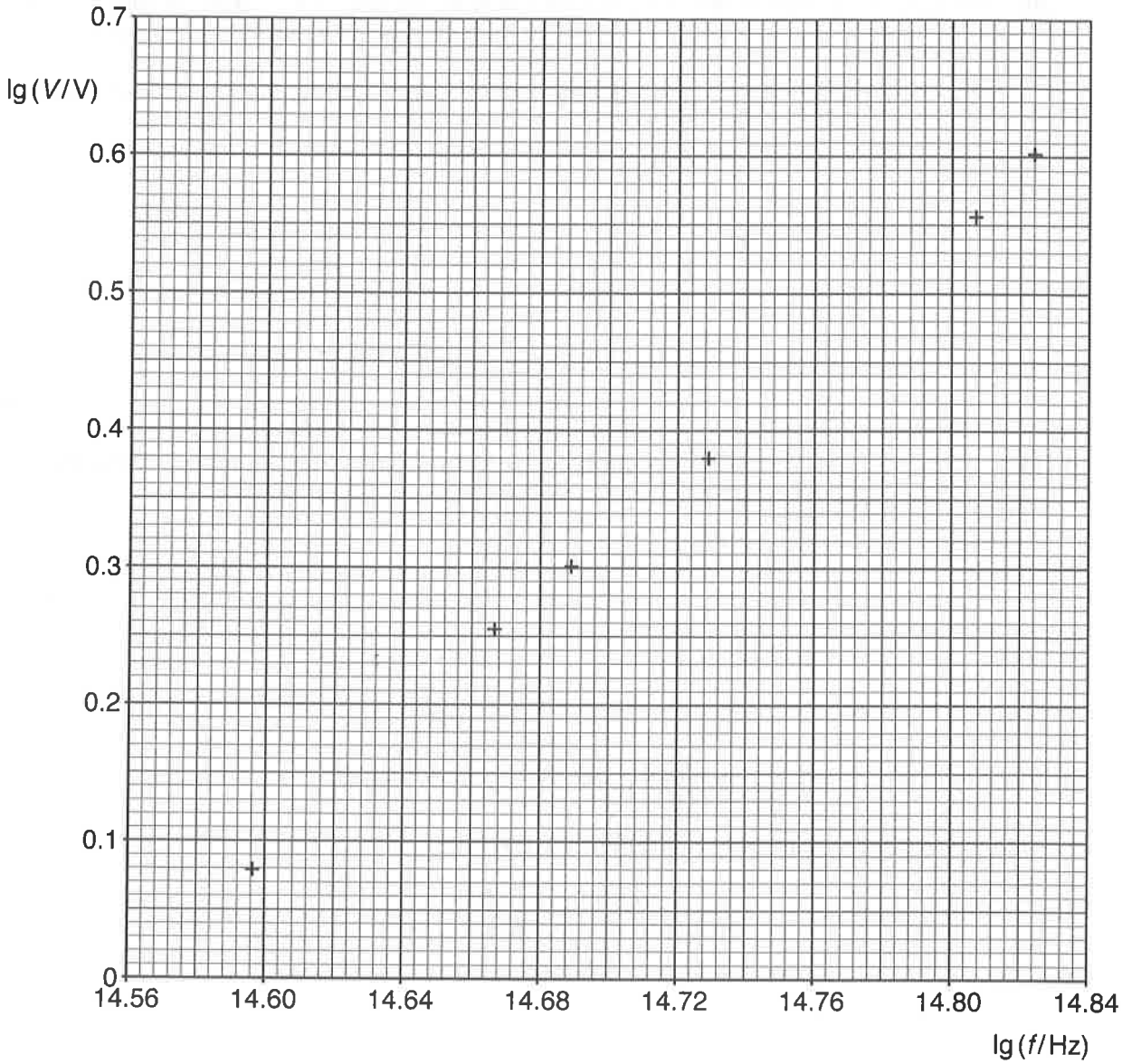

Fig. 7.1

(ii) A 10 W LED emits photons of energy 3.8×10^{-19} J.

Determine the number of photons released in 1.0 minute.

number = ... [2]

(iii) An LED operating under normal conditions emits photons of wavelength 520 nm. It is connected to a power supply of e.m.f. 4.5 V with negligible internal resistance.

Calculate the resistance of the series resistor required for safe operation of the LED.

resistance = ... Ω [2]

(d) Use your understanding of current and of charge to explain the meaning of 730 mAh.

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.....[2]

(e) Luminous flux represents the light power output from a lamp.

Use values from the passage to determine the ratio

$$\frac{\text{efficiency of LED}}{\text{efficiency of incandescent lamp}}.$$

ratio = ... [2]

(f) Data comparing the brightness and cost of use of comparable LED, CFL and incandescent lamps are given in Table 7.2.

Table 7.2

	LED	CFL	incandescent
projected lifespan / hours	50 000	10 000	1200
brightness / lumens	800	800	840
power rating / watts	10	14	60
cost per lamp	$35.95	$3.95	$1.25
bulbs needed for 50 k hours of use	1	5	42

The cost of electricity is $0.22 per kWh.

(i) Use the data from the table and information from the passage to explain why LEDs and CFLs are replacing incandescent lamps in the home.

.....

.....[2]

(ii) The Land Transport Authority (LTA) has decided to replace all the CFLs used in traffic lights in Singapore with LEDs.

By considering the operating costs of one traffic light, using data from Table 7.2, produce an argument for or against this decision by the LTA. You should make calculations with clear working in support of your argument.

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.....[3]

(iii) Suggest why incandescent lamps may be used in traffic lights in some cities in Canada that have regular heavy snowfalls in winter.

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.....[1]

[Total: 22]

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