Unit 13 · Light

ANSWER KEY · FOR TEACHERS

Full marks 49

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. convex
2. concave
3. plano-convex
4. power
5. diopter
6. magnification
7. real
8. virtual

Each carries 0.5 mark. K · 4

2 Label the diagram

1. objective
2. final image (virtual)
3. first image (real)
4. eyepiece

Each carries 0.5 mark. K · 2

3 True or false

i. ✗ **False**: It bends light more strongly: the size of the power tells how strongly, and the sign only which way. U · 3

ii. ✓ **True**

iii. ✗ **False**: It means the image is virtual and on the object's side of the lens.

iv. ✓ **True**

v. ✗ **False**: The objective has the shorter focal length.

vi. ✓ **True**

Each carries 0.5 mark.

4 Multiple choice

i. **b.** −25 cm A · 1

$f = \frac{1}{P} = \frac{1}{-4} = -0.25$ m $= -25$ cm. The minus sign means a concave lens.

ii. **b.** 20 cm from the lens, the same size A · 1

$\frac{1}{v} = \frac{1}{10} - \frac{1}{20} = \frac{1}{20}$, so $v = 20$ cm and $m = \frac{20}{20} = 1$. The object is at 2F, so the image is at 2F on the other side, real, inverted and the same size.

iii. **d.** between F and the lens U · 1

Only then do the rays still spread after the lens, so they meet only when traced back, giving a virtual, upright, magnified image (a magnifying glass).

iv. **b.** real, inverted and magnified K · 1

The object is just beyond the objective's focus (between F and 2F), so its image is real, inverted and magnified. In a telescope the first image is diminished instead, because the object is very far away.

v. **b.** 50 cm A · 1

P = +3 + (−1) = +2 D, so $f = \frac{1}{2}$ m = +50 cm, a converging combination.

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5 Very short answers

a. MARKING SCHEME — K · 1

✓ About 25 cm.

b. MARKING SCHEME — U · 1

✓ 6 worked out.

c. MARKING SCHEME — A · 1

✓ 400× worked out.

6 Short answers

a. MARKING SCHEME — U · 2

✓ A concave lens spreads light, so its focus is virtual and its focal length is negative in the sign convention.

✓ $P = \frac{1}{f}$, so its power is negative too.

b. MARKING SCHEME — U · 2

✓ A larger objective collects more light, so faint objects can be seen.

✓ It also shows finer detail.

c. MARKING SCHEME — U · 2

✓ Just beyond the focus, the objective forms a real, inverted, magnified image in the tube, which the eyepiece magnifies again.

✓ Inside the focus it would form a virtual image on the object's side, which the eyepiece couldn't use.

d. MARKING SCHEME — U · 2

✓ Magnification tells how many times the image is taller than the object; power tells how strongly the lens converges or diverges light.

✓ Magnification has no unit and depends on where the object is; power is in diopters and is fixed for a lens (or any other correct difference).

7 Long answers

a. ANSWER — U · 4

Lens formula: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$. Sign convention: all distances from the optical center; distances of real objects and real images positive, of virtual images negative; f positive for a convex lens, negative for a concave one.

Derivation (as in the figure in the book): object AB at OA $= u$, image A′B′ at OA′ $= v$, focus F at OF $= f$; the ray from B parallel to the axis meets the lens at Q, so OQ = AB.

Triangles ABO and A′B′O are similar: $\frac{A'B'}{AB} = \frac{v}{u}$.

Triangles OQF and A′B′F are similar: $\frac{A'B'}{OQ} = \frac{v-f}{f}$.

Since OQ = AB, $\frac{v}{u} = \frac{v-f}{f}$, so vf = uv − uf, or uv = vf + uf. Dividing by uvf: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$.

MARKING SCHEME

✓ The formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ and its signs: real distances positive, virtual negative, f positive for convex.

✓ Triangles ABO and A′B′O: $\frac{A'B'}{AB} = \frac{v}{u}$.

✓ Triangles OQF and A′B′F: $\frac{A'B'}{OQ} = \frac{v-f}{f}$, with OQ = AB.

✓ So uv = vf + uf; dividing by uvf gives the formula.

b. ANSWER

Function: to see distant objects, such as the Moon, planets and stars, magnified.

Structure: an objective lens of long focal length and large aperture facing the object; an eyepiece of short focal length near the eye; a tube, in two sliding parts, holding them on one axis so their distance

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can be adjusted. U · 4

Working: parallel rays from the distant object are brought by the objective to its focus, forming a real, inverted, diminished image there. In normal adjustment this image is at the focus of the eyepiece too, so the rays leave the eyepiece parallel and the final image, inverted, is at infinity, seen with a relaxed eye. The length is $f_o + f_e$ and the magnifying power $M = \frac{f_o}{f_e}$. The ray diagram is as in the figure in the book (Practical 22).

MARKING SCHEME

- ✓ Structure: an objective of long focal length and large size, an eyepiece of short focal length, a sliding tube.
- ✓ The objective forms a real, inverted, diminished image at its focus.
- ✓ This is at the eyepiece's focus too, so the rays leave parallel and the final image is inverted, at infinity.
- ✓ $M = \frac{f_o}{f_e}$, length $f_o + f_e$; a ray diagram with both lenses, F and arrows.

8 Numerical problems

a. **ANSWER** A · 3

$$\frac{1}{v} = \frac{1}{12} - \frac{1}{8} = \frac{2-3}{24} = -\frac{1}{24} \qquad v = -24 \text{ cm}$$

$m = \frac{v}{u} = \frac{-24}{8} = -3$, so the image is $3 \times 3 = 9$ cm tall (the minus sign: virtual and upright).

24 cm from the lens on the object's side: virtual, upright, 9 cm tall.

MARKING SCHEME

- ✓ $\frac{1}{v} = \frac{1}{12} - \frac{1}{8} = -\frac{1}{24}$, so v = −24 cm.
- ✓ m = −24 ÷ 8 = −3, so the image is 9 cm tall.
- ✓ On the object's side: virtual and upright.

b. **ANSWER** A · 3

$$\frac{1}{v} = -\frac{1}{20} - \frac{1}{60} = \frac{-3-1}{60} = -\frac{4}{60} \qquad v = -15 \text{ cm} \qquad m = \frac{v}{u} = \frac{-15}{60} = -0.25$$

15 cm from the lens on the object's side: virtual, upright, a quarter of the size.

MARKING SCHEME

- ✓ f = −20 cm: $\frac{1}{v} = -\frac{1}{20} - \frac{1}{60} = -\frac{4}{60}$.
- ✓ v = −15 cm, on the object's side.
- ✓ m = −0.25: virtual, upright, a quarter of the size.

c. **ANSWER** A · 4

Objective: $\frac{1}{v_o} = \frac{1}{2} - \frac{1}{2.5} = \frac{0.5}{5} = \frac{1}{10}$, so $v_o = 10$ cm and $m_o = \frac{10}{2.5} = 4$.

Eyepiece: $\frac{1}{u_e} = \frac{1}{5} + \frac{1}{25} = \frac{6}{25}$, so $u_e = 4.17$ cm and $m_e = \frac{25}{4.17} = 6$.

$M = 4 \times 6 =$ **24**; the lenses are 10 + 4.17 = **14.2 cm** apart.

MARKING SCHEME

- ✓ $v_o = 10$ cm, so $m_o = 4$.
- ✓ $u_e = 4.17$ cm, so $m_e = 6$.
- ✓ M = 4 × 6 = 24.
- ✓ Distance between the lenses = 10 + 4.17 = 14.2 cm.

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d. **ANSWER** A · 3

$11 f_e = 55$, so $f_e =$ **5 cm** (+20 D) and $f_o =$ **50 cm** (+2 D).

MARKING SCHEME

✓ $f_o + f_e = 55$ and $f_o = 10 f_e$.
✓ $f_e = 5$ cm, $f_o = 50$ cm.
✓ Powers +20 D and +2 D.

9 Think

ANSWER HA · 3

Microscope: the 2 cm lens as the objective (very short focal length, close to the object) and the 5 cm lens as the eyepiece. **Telescope:** the 50 cm lens as the objective and the 2 cm lens as the eyepiece, which gives $M = \frac{50}{2} = 25$ in a tube 52 cm long (with the 5 cm eyepiece it would magnify only 10 times). The 50 cm lens would be useless as a microscope objective: the first image would be far away and hardly magnified.

MARKING SCHEME

✓ Microscope: 2 cm objective (very short focal length), 5 cm eyepiece.
✓ Telescope: 50 cm objective, 2 cm eyepiece.
✓ The telescope then magnifies $50 \div 2 = 25$ times, more than the 10 times with the 5 cm eyepiece.

10 Activity: Find the focal length of a convex lens

(not marked)

WHAT STUDENTS SHOULD FIND

Every pair of u and v gives nearly the same f, close to the rough value from the window. Where the candle is at $2f$, the image is also at $2f$ and the same size as the flame. The nearer the candle comes to f, the farther away and bigger the image, until at f no image forms on the card at all.

See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **Rays of Light** (exhibit): Put the convex lens in the three beams and find where they meet, the principal focus; a concave lens spreads the beams apart.
- **The Single Lens Camera** (exhibit): The lens casts a real, upside-down image of the scene on the box's screen: the light really meets there.
- **The Fresnel Lens** (exhibit): Look through it at the letters: they look bigger and upright, a convex lens used as a magnifying glass, kept thin by cutting it into rings.
- **The Water Bowl Magnifier** (exhibit): A bowl of water magnifies like a lens: find where the pebbles look largest, as people once did with water-filled glass spheres.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	8	21	17	3	**49**

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