# Exercise walk-through

## The diffraction grating ▪ 8.4

eXercise

# You must be able to

- use $d \sin \theta = n\lambda$ in **both** directions (find an angle; find the grating)
- find the slit spacing from **lines per mm** and the **highest order**
- describe using a grating to measure **wavelength**

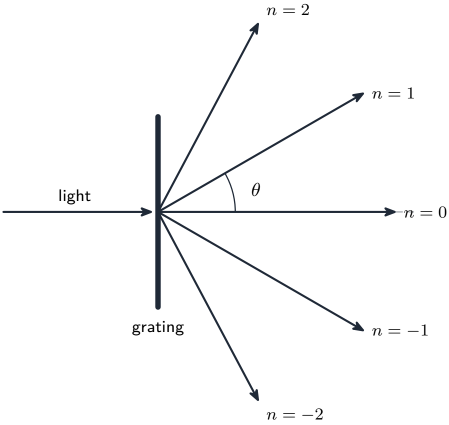
# Method — The grating equation

A grating has many equally spaced slits, slit spacing $d$. Bright maxima (orders $n$) appear where

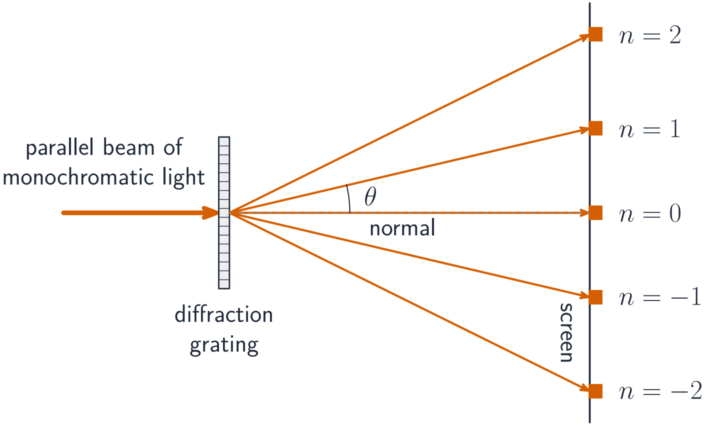
$$d \sin\theta = n\lambda.$$

**Worked example (find the angle).** 500 lines/mm, $\lambda = 600$ nm:
$d = \dfrac{1}{500}$ mm $= 2.0 \times 10^{-6}$ m; $\sin\theta = \dfrac{n\lambda}{d} = \dfrac{600 \times 10^{-9}}{2.0 \times 10^{-6}} = 0.30$, so $\theta \approx 17°$.

# Method — The grating equation



# Method — The grating equation




*A diffraction grating spreads the orders*

# Method — Working backwards — find the grating

Exam questions often **give** an order's angle and ask for the grating. Rearrange to $d = \dfrac{n\lambda}{\sin\theta}$, then **lines per mm** $= \dfrac{1}{d \text{ (in mm)}}$.

**Worked example.** The **second-order** $(n = 2)$ maximum for $\lambda = 730$ nm is at $\theta = 35°$. Then $d = \dfrac{2 \times 730 \times 10^{-9}}{\sin 35°} = \dfrac{1.46 \times 10^{-6}}{0.574} = 2.55 \times 10^{-6}$ m. In mm, $d = 2.55 \times 10^{-3}$ mm, so **lines per mm** $= \dfrac{1}{2.55 \times 10^{-3}} \approx 390.$

# Method — Slit spacing and highest order

$N$ lines per mm $\to$ $d = 10^{-3}/N$ m. Since $\sin\theta \le 1$, the **highest order** is $n_{\max} = \lfloor d/\lambda \rfloor$.

# Method — Finding wavelength

Shine parallel light normally on the grating, measure $\theta_1$ for the first order, then $\lambda = d \sin\theta_1$. A grating gives **sharper** maxima than a double slit (many slits add).

## Practice 2.1 ▪ 1 mark

State what $d$ represents in $d \sin \theta = n\lambda$.

# Solution 2.1

**Worked steps**

The **slit spacing** — the (centre-to-centre) distance between adjacent slits **B1**.

# Practice 2.2 ▪ 2 marks

A grating has $500$ lines per mm. Find the slit spacing $d$ in metres.

# Solution 2.2

Method: The grating equation

## Worked steps

$$d = \frac{1}{500}\ \text{mm} = \frac{10^{-3}}{500} = 2.0 \times 10^{-6}\ \text{m} \quad \text{M1}\ \text{A1}.$$

# Practice 2.3 ▪ 1 mark

State **one** reason a grating gives **sharper** maxima than a double slit.

# Solution 2.3

Method: Finding wavelength

**Worked steps**

Many slits contribute, so the maxima are **sharper/brighter** and other directions are more completely cancelled **B1**.

# Practice 2.4 ▪ 1 mark

Write the formula for the **highest order** observable.

# Solution 2.4

Method: Slit spacing and highest order

**Worked steps**

$n_{\max} = \lfloor d/\lambda \rfloor$ (the largest integer with $\sin\theta \leq 1$) **B1**.

# Exam-style 3.1 ▪ 3 marks

A grating with $500$ lines per mm is illuminated normally by light of wavelength $600$ nm. Calculate the angle of the **first-order** maximum.

# Solution 3.1

Method: The grating equation

## Worked steps

$d = 2.0 \times 10^{-6}$ m **M1**; $\sin\theta = \dfrac{(1)(600 \times 10^{-9})}{2.0 \times 10^{-6}} = 0.30$ **M1**; $\theta = 17^\circ$ **A1**.

# Exam-style 3.2 ▪ 2 marks

For the same grating and wavelength, calculate the **highest order** that can be seen.

# Solution 3.2

Method: Finding wavelength

**Worked steps**

$d/\lambda = \dfrac{2.0 \times 10^{-6}}{600 \times 10^{-9}} = 3.33$ **M1**; highest order $n = 3$ ($n = 4$ needs $\sin\theta > 1$) **A1**.

# Exam-style 3.3 ▪ 4 marks

A grating has $600$ lines per mm. Light of wavelength $590$ nm is incident normally on it. **Determine** the highest order of maximum that can be observed, and **explain** what limits it.

# Solution 3.3

## Worked steps

$d = \dfrac{1\ \text{mm}}{600} = 1.67 \times 10^{-6}$ m **M1**; the largest possible diffraction angle is $90°$, where $\sin\theta = 1$ **M1**, so $n_{\text{max}} = \dfrac{d}{\lambda} = \dfrac{1.67 \times 10^{-6}}{590 \times 10^{-9}} = 2.8$ **M1**. An order must be a whole number, so the highest observed is the **2nd order** **A1** — $n$ cannot be rounded up, because $\sin\theta$ can never exceed 1.

# Exam-style 3.4 ▪ 3 marks

Describe how a diffraction grating can be used to **measure the wavelength** of light.

# Solution 3.4

## Worked steps

Shine **parallel monochromatic** light normally on the grating B1; measure the **angle** $\theta$ of a known order $n$ from the straight-through direction B1; calculate $\lambda = \dfrac{d \sin\theta}{n}$ B1.

# Exam-style 3.5 ▪ 1 mark

A grating with **more** lines per mm (smaller $d$) is used. The diffraction angles become:

**A** smaller

**B** larger

**C** unchanged

**D** zero

# Solution 3.5

Method: The grating equation

**A** smaller

**B** larger ✓

**C** unchanged

**D** zero

**Worked steps**

**B** — larger (smaller *d* gives larger $\sin\theta$ for each order).