

17.3 Damped and forced oscillations, resonance

Name: _____ Class: _____ Date: _____

Total: 23 marks

KEY WORDS resonance 共振 • driving frequency 驱动频率 • natural frequency 固有频率
• forced oscillation 受迫振动 • critical damping 临界阻尼

Objective

Build the skills to answer exam questions on **damping** and **resonance**.

You must be able to:

- describe **light**, **critical** and **heavy** damping and sketch their graphs
- explain **resonance** and the condition for it

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

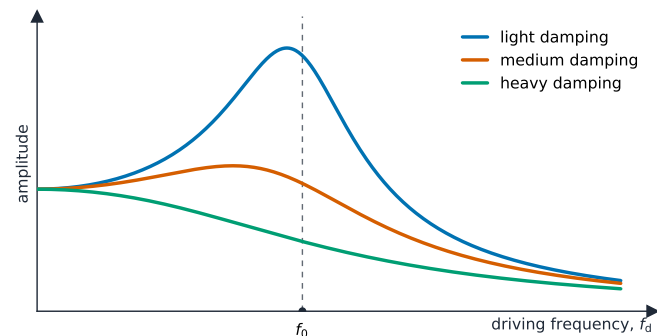
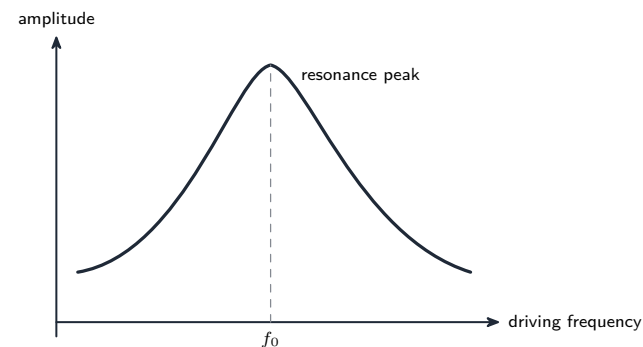
■ Damping

A **resistive force** removes energy, so the amplitude **shrinks** — this is **damping**:

- light**: amplitude dies away slowly over many cycles;
- critical**: returns to equilibrium **fastest** with **no overshoot**;
- heavy**: returns slowly, no oscillation.

■ Resonance

A system **forced** to oscillate has the largest amplitude when the **driving frequency** equals its **natural frequency** f_0 — this is **resonance**:



resonance: max amplitude near f_0 • lighter damping $\Rightarrow$ sharper peak

The resonance curve and damping

More damping makes the resonance peak **lower and broader**.

2 Practice

Now apply the methods above.

2.1 State what causes **damping**.

[1]

2.2 Name the **three** types of damping. [2]

2.3 State what is meant by **resonance**. [1]

2.4 State the condition for resonance to occur. [1]

3 Exam-style questions

3.1 **Critical** damping is the damping that: [1]

- **A** lets the system oscillate forever
- **B** returns the system to equilibrium fastest, without overshooting
- **C** returns the system to equilibrium most slowly
- **D** increases the amplitude

3.2 Describe how the **amplitude** of a forced oscillation changes as the driving frequency is increased through the natural frequency. [3]

3.3 Give **one** example each of where **light** damping and **critical** damping are useful. [2]

3.4 Explain what happens to the **resonance peak** when more damping is added. [2]

3.5 A machine part is mounted on rubber blocks. When the machine runs, the part is driven into oscillation, and a technician measures the amplitude of the part at each driving frequency.

(a) **State** the conditions needed for **resonance** to occur. [2]

(b) The amplitude peaks sharply at a driving frequency of 24 Hz. **State** what this tells you about the part, and **determine** its natural period. [2]

(c) The rubber blocks are replaced with stiffer ones, which **increase** the natural frequency of the part but also **increase** the damping. On one set of axes, **sketch** two curves of amplitude against driving frequency: the original mounting, labelled A, and the stiffer one, labelled B. [4]

(d) **Explain** why an engineer would prefer the stiffer, more heavily damped mounting even though the machine's own running frequency cannot be changed. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

- a **resistive force** (friction / drag / air resistance) removing energy from the oscillator

2.2

- **light**, **critical** and **heavy** damping

2.3

- the condition where a forced oscillation reaches its **maximum amplitude**

2.4

- the **driving frequency equals the natural frequency** of the system

3.1 B

- critical damping **returns to equilibrium fastest without overshooting**

3.2

- the amplitude **rises** as the driving frequency approaches the natural frequency
- reaching a **maximum at** f_0 (resonance)
- then **falls** again as the frequency increases past f_0

3.3

- light damping — e.g. a pendulum/clock or musical instrument (sustained oscillation)
- critical damping — e.g. a galvanometer/voltmeter needle or car suspension/door closer (quick settle)

3.4

- the peak becomes **lower** (smaller maximum amplitude)
- and **broad**er (occurs over a wider range of frequencies)

3.5

(a) the system is driven by a **periodic force** whose frequency equals the **natural frequency** of the system

- there is a **maximum transfer of energy** to it, so its amplitude becomes maximum

(b) the natural frequency of the part is 24 Hz

$$T = \frac{1}{f} = \frac{1}{24 \text{ Hz}} = \mathbf{0.042 \text{ s}}$$

(c) curve A: a sharp peak at 24 Hz

- curve B: its peak is at a **higher** frequency, is **lower** in amplitude, and is **broad**er — heavier damping flattens and widens the resonance curve; both curves start at a non-zero amplitude at zero frequency and fall away at high frequency

(d) the machine's running frequency is now **further from** the part's natural frequency, so the part is driven well away from resonance

- the extra damping lowers the amplitude at every frequency, so even at resonance the oscillation would be smaller and less likely to cause damage