5.3 Collisions, friction, power and fluid forces

Name: _____ Class: _____ Date: _____ **Total: 30 marks**

KEY WORDS coefficient of restitution • friction • power • drag • lift • Magnus effect

Objective

Build the skills to answer HL exam questions on **collisions** , **friction** , **work** and **power** , and **fluid forces** : drag, lift and the Magnus effect, and how the environment changes them.

You must be able to:

- calculate and interpret the coefficient of restitution
- distinguish static and dynamic friction
- calculate work and power
- explain drag, lift and the Magnus effect, and the effects of altitude and conditions

1 Key knowledge and worked examples

■ Collisions, friction, power and fluids

Coefficient of restitution (e) describes how "bouncy" a collision is: $e = \dfrac{\text{speed of separation}}{\text{speed of approach}}$; for a ball dropped on a fixed surface, $e = \sqrt{\dfrac{h_{\text{bounce}}}{h_{\text{drop}}}}$. $e = 1$: no energy lost; $e = 0$: no bounce. It depends on both surfaces, the temperature and the impact speed.

Friction acts along a surface, against sliding. **Static** friction (no sliding yet) is larger than **dynamic** (sliding) friction. It depends on the surfaces (studs, rubber, ice) and the normal force.

$$\text{work } W = Fd \ \text{(J)} \qquad \text{power } P = \frac{W}{t} = Fv \ \text{(W)} \qquad \text{lifting: } W = mgh$$

Drag opposes motion through air or water: **surface** drag (friction with the skin or clothing), **form** (pressure) drag (shape and frontal area) and **wave** drag (at the water surface). Drag rises roughly with v^2, so the power to overcome it rises roughly with v^3.

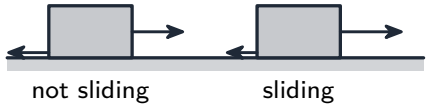
Lift is a force at right angles to the flow (a discus or ski jumper at a good **angle of attack**). **Magnus effect:** a spinning ball drags air round with it; air on one side moves faster and has **lower pressure**, so the ball swerves towards that side: **topspin** makes a ball dip, **backspin** makes it float.

Environment: at **altitude** the air is less dense, so there is less drag: sprints, jumps and throws benefit, while endurance events suffer from the lower partial pressure of oxygen. Warm, humid air is also slightly less dense; wind and water temperature matter too.

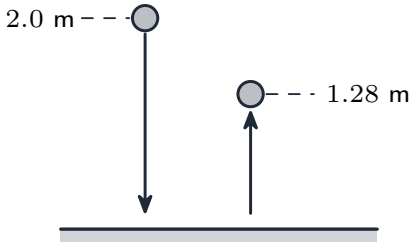
Answer shapes: for fluids, name the force, its direction, and the pressure or speed difference that causes it.

2 Practice

2.1 Distinguish between static and dynamic friction. [2]

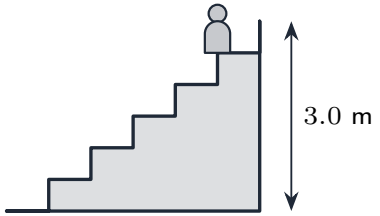


2.2 A ball is dropped from 2.0 m and bounces to 1.28 m. Calculate the coefficient of restitution and state what it shows. [3]

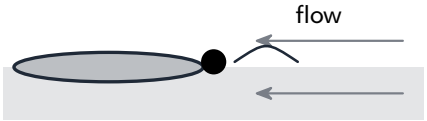


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2.3 A 70 kg athlete runs up stairs with a vertical height of 3.0 m in 2.5 s. Calculate the work done against gravity and the mean power ($g = 9.81$ m s^{-2}). [3]



2.4 A swimmer wants to reduce drag.



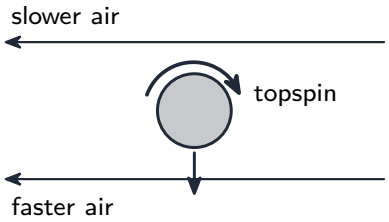
(a) Identify **three** types of drag acting on the swimmer. [3]

(b) Suggest how a swimsuit can reduce **one** of them. [1]

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3 Exam-style questions

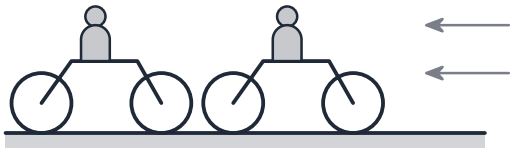
3.1 A tennis player hits the ball with heavy topspin.



(a) Explain why topspin makes the ball dip. [3]

(b) Name this effect. [1]

3.2 A cyclist meets 20 N of air drag at 10 m s^{-1}. Drag is proportional to speed squared.

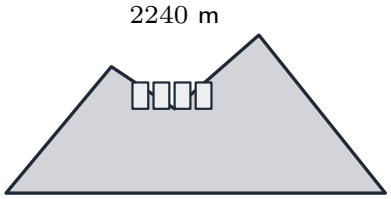


(a) Calculate the drag at 15 m s^{-1}. [2]

(b) Calculate the power needed to overcome this drag at 15 m s^{-1}. [2]

(c) Explain why riding close behind another cyclist (drafting) saves energy. [2]

3.3 The 1968 Olympic Games were held in Mexico City, about 2240 m above sea level.



Discuss how the altitude was likely to affect performances in different events. [8]

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Solutions

Marking: **M1** a correct method, **A1** the correct answer, **B1** an independent mark.

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

2.1

static friction acts when the surfaces are not yet sliding; it matches the applied force up to a maximum; dynamic friction acts while sliding and is smaller than the maximum static friction

2.2

$e = \sqrt{1.28 \div 2.0} = \sqrt{0.64} = \mathbf{0.8}$; the collision is fairly elastic, but some energy is lost as heat and sound

2.3

$W = mgh = 70 \times 9.81 \times 3.0 \approx \mathbf{2060}$ J; $P = 2060 \div 2.5 \approx \mathbf{820}$ W

2.4

(a) surface (skin friction) drag; form (pressure) drag; wave drag

(b) a smooth, tight suit reduces surface drag / compresses the body to reduce form drag

3.1

(a) the top of the ball moves against the oncoming air, the bottom moves with it; air below the ball moves faster than air above; so pressure is lower below and higher above, giving a downward force

(b) the Magnus effect

3.2

(a) $20 \times (15 \div 10)^2 = \mathbf{45}$ N

(b) $P = Fv = 45 \times 15 = \mathbf{675}$ W

(c) the rider in front pushes the air aside, leaving a low-pressure, slower-moving zone behind; the following rider meets less form drag, so needs less power for the same speed

3.3

award up to [8]: air at altitude is less dense; so drag is lower; short, fast events gain: sprints, jumps and throws, e.g. many sprint and jump records were set there, including Beamon's long jump; lower air pressure means a lower partial pressure of oxygen; so less oxygen reaches the muscles and aerobic events of more than about 2 minutes were slower; athletes from high-altitude regions were less affected, being acclimatized; conclusion: altitude helps anaerobic, high-speed events and harms endurance events

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