Section Three: Comprehension **20% (36 Marks)**

Question 1 **(18 marks)**

The Physics of Skipping Stones

(Adapted from: The Mystery of the Skipping Stone, Physics World Vol 19 No 2 February 2006 Bocquet L and Clanet C)

Champion stone skipper Kurt Steiner has been stopped going through customs with bags full of rocks and always carries a five-sided stone in his pocket.

In 2002 an American named Kurt Steiner set a new world record when he threw a stone across a river in Pennsylvania and made it bounce 40 times. Most people will not have been quite as successful as Steiner, but many will be familiar with the principle of stone skipping: to throw a flattish stone across the surface of a body of water so that it bounces as many times as possible.

It has been shown that the formula that relates collision time (of a stone with the water surface) and velocity for a stone is given by;

$$T = \left(\frac{MR}{\rho S}\right)\left(\frac{1}{v}\right)$$

where:
T is the collision time (s)
M is the mass of the stone (kg)
R is the radius of the stone (m)
ρ is the density of water (kg m^{-3})
S is the cross-sectional area of the stone (m^2)
v is the velocity of the stone (m s^{-1})

The data below pertains to a stone of dimensions:

M = 15 g; R = 3 cm; S = 3.6 x 10^{-6} m^2

Question 1 (continued)

Collision Time (ms) T (ms)	Velocity (m s^{-1}) v (ms^{-1})	v^{-1} (sm^{-1})
56	2	0.50
37	3	0.33
22	5	0.20
16	7	0.14
12	9	0.11
10	11	0.091
7.5	15	0.067

a) Given the formula above, what should you plot to obtain a linear graph? [2]

Plot T (vertical axis) VS v^{-1} (horizontal axis)

b) Use the third column in the table to process the given data to allow you to plot a linear graph. Label the column with appropriate units. [3]

c) Plot the graph on the graph paper provided. [5]

d) Determine the gradient of your line. [2]

Points on BFL (0.091, 10) (0.50, 56)

$$\text{gradient} = \frac{(56-10)\times 10^{-3}}{(0.50-0.091)} = \frac{46\times 10^{-3}}{0.409} = 0.112$$

e) Use the gradient of your curve to determine the density of water. [2]

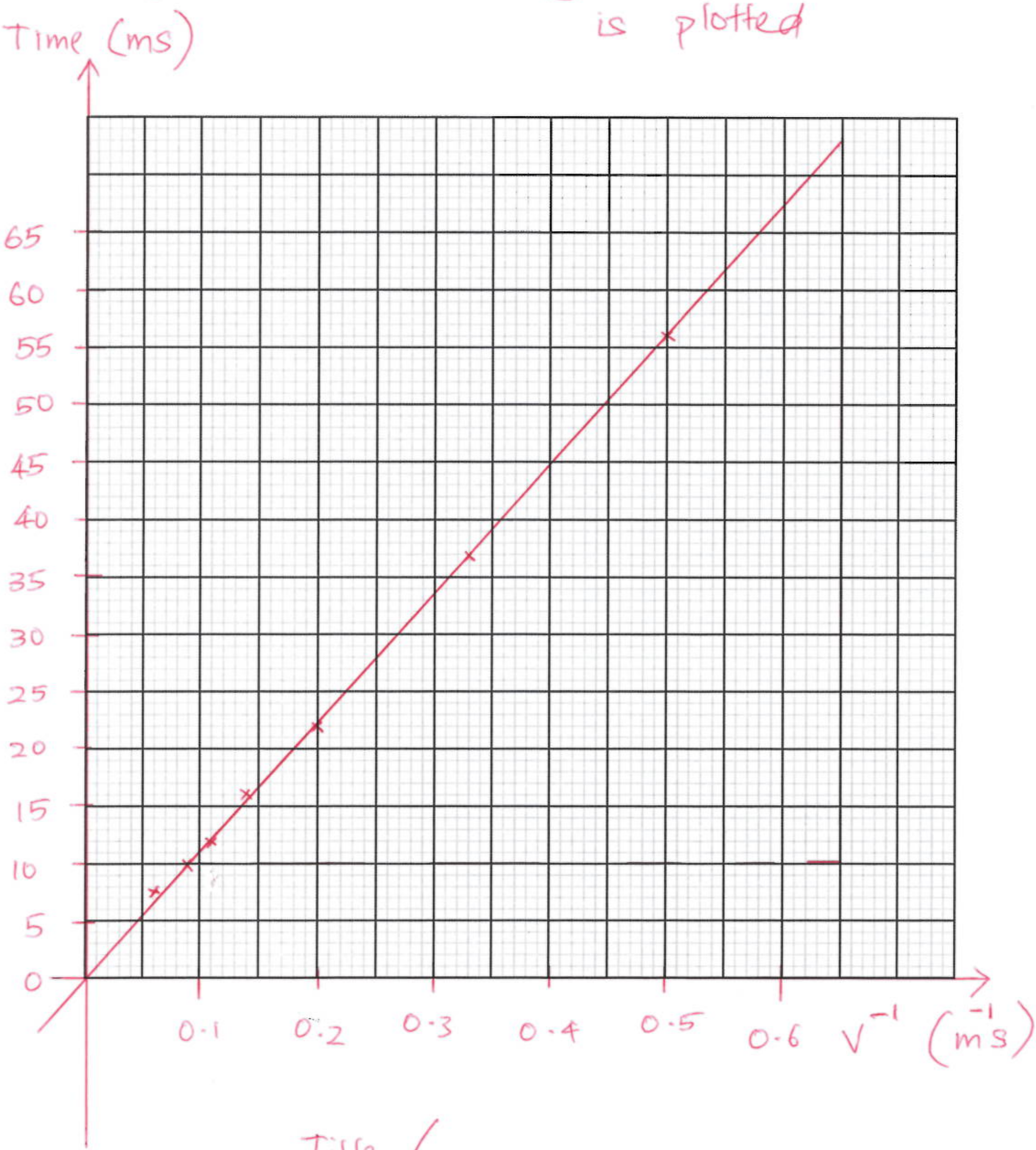
$$T = \frac{MR}{\rho S}\left(\frac{1}{V}\right)$$

$y = k x$ where k is the gradient

$$\frac{15\times 10^{-3} \times 3\times 10^{-2}}{\rho \times (3.6\times 10^{-6})} = 0.112$$

$$\rho = 1116 \text{ kg m}^{-3}$$
$$= 1.11 \times 10^{3} \text{ kg m}^{-3}$$

A graph of T (ms) against V^{-1} ($s\,m^{-1}$) is plotted



Title ✓

Axes Labelled & Units ✓

Points plotted accurately ✓

Linear Scales ✓

Line of Best Fit ✓

Question 1 (continued)

Experiments have also shown that a bouncing stone must spin with a certain minimum rotational velocity if it is to be stable i.e. if the angle between the plane of the stone and the water surface is to remain constant. To remain stable, a stone typically needs to rotate at least once during its collision time. If this rotation does not take place, the stone's collision becomes quite complex and a second bounce becomes much less likely.

f) If a stone is to rotate at least once during its collision time, what must the minimum spin velocity be equal to? [1]
(Hint – this does not require a numerical answer)

The inverse of collision time ✓

g) People who are good at stone skipping, intuitively rotate stones with a flick from the finger. Why do they do this? [1]

* gives the stone increased spin (or rotational velocity) OR ✓

* increase the likelihood that stone rotate once during collision

Researchers found that, surprisingly, the stone does not slow down during the skipping process, but rather the stone's trajectory 'flattens' with time. This is because the angle with which the stone moves relative to the water dictates that the stone displaces more water when it moves down than rises. This results in a smaller transfer of momentum in the latter stage of each skip and therefore in reduced lift. When the stone no longer has enough energy to jump, it simply surfs over the water before finally sinking.

The number of skips is also determined by the type of stone used and the angle at which it is thrown. And as all stone skippers know, the flatter the stone, the better!

h) The passage describes the stone's trajectory as 'flattening'. Explain what this means with regards to changes in the horizontal and vertical components of the velocity. [1]

Horizontal velocity stays the same
vertical velocity decreases ✓

i) Why would there be reduced lift in the latter stages of the motion? [1] ✓

one valid reason

stone displaces more water on way down than on up

OR

greater the displacement, greater the force on stone; greater the change in momentum

OR

↑ component of velocity decreases; ↓ amount of water displaced