# CAP High School/CEGEP Prize Exam

April 6,2022

9:00 - 12:00

## Student Information Sheet

The following information will be used to inform students and schools of the exam results, to determine eligibility for some subsequent competitions and for statistical purposes. Only the marking code, to be assigned by the local examination committee, will be used to identify papers for marking.

| Marking Code: |
|---|

This box must be left empty.

**PLEASE PRINT CLEARLY IN BLOCK LETTERS**

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Student First Name | | | | | | | | | | | | | | | | | | | | | | | | |
| Student Last Name | | | | | | | | | | | | | | | | | | | | | | | | |
| Teacher Name | | | | | | | | | | | | | | | | | | | | | | | | |

Address: (Street number and Apt) _____

(City and Province) _____ (Postal Code)_____

Telephone: (  ) _____ Email: _____

School: _____ Grade: _____

Date of Birth: _____

Gender: _____ Citizenship: _____

If you are not a Canadian citizen, what is your Immigration Status? _____

For how many years have you studied in a Canadian school? _____

Would you prefer further correspondence in French or English? _____

*By signing this page I agree that, if my score on this Exam is in the top 20 nationally or in the top 6 in my province, my name, my school's name, and my ranking can be published.*

Student's signature: _____

Sponsored by:

Canadian Association of Physicists;
Canadian Physics Olympiad;
Department of Physics and Astronomy,
University of British Columbia.

### 2022 Canadian Association of Physicists Highschool/Cegep Prize Exam

This is a three-hour exam. National ranking and prizes will be based on students' performance on sections A and B of the exam. Performance on questions in section A will be used to determine whose written work in section B will be marked for prize consideration by the CAP Exam National Committee. Section A consists of 25 multiple-choice questions. The questions in section B span a range of difficulty, and may require graphing and/or measurement on the graph. Be careful to gather as many of the easier marks as possible before venturing into more difficult territory. When you are unable to solve any part of a question, you may assume a likely answer to that part and attempt the rest of the question anyway.
Non-programmable calculators may be used. Answer the multiple-choice questions ***on the answer sheet*** provided. Most importantly: write your solutions to the three long problems on ***three separate sheets*** as they will be marked by people in different parts of Canada. Good luck.
**Notice**: Full marks will be given to students who provide full correct solutions to problems in Section B. Partial marks will be given for partial solutions. There are no penalties for incorrect answers. The questions are not of equal difficulty. Remember that we are challenging the best physics students in Canada; it is possible that even the best papers may not achieve an overall score of 80%. This Exam is meant to be challenging!

#### Data

Speed of light $c = 3.00 \times 10^8$ m/s
Speed of sound in air = 343 m/s
Gravitational constant $G = 6.67 \times 10^{-11}$ N·m$^2$/kg$^2$
Acceleration due to gravity $g = 9.81$ m/s$^2$
Standard atmospheric pressure $P_0 = 1.01 \times 10^5$Pa
Density of fresh water $\rho = 1.00 \times 10^3$ kg/m$^3$
Density of ice $\rho_i = 916$ kg/m$^3$
Specific heat of water $C_w = 4186$ J/(kg·K)
Specific heat of ice $C_i = 2050$ J/(kg·K)
Latent heat of water $L_w = 2260$ kJ/kg
Latent heat of ice $L_i = 334$ kJ/kg
Fundamental charge $e = 1.60 \times 10^{-19}$ C
Mass of an electron $m_e = 9.11 \times 10^{-31}$ kg
Mass of a proton $m_p = 1.67 \times 10^{-27}$ kg
Planck's constant $h = 6.63 \times 10^{-34}$ J·s
1 eV $\approx 1.602 \times 10^{-19}$ J
Electrostatic constant $k = 1/4\pi\epsilon_0 = 8.99 \times 10^9 N \cdot m^2/C^2$
Permittivity of free space $\epsilon_0 = 8.854 \times 10^{-12}$ C$^2$/N·m$^2$
Boltzmann's constant $k_B = 1.38 \times 10^{-23}$ J/K
Stefan–Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ W/m$^2$· K$^4$
Astronomical Unit (approximate distance from the Sun to the Earth) 1 AU $= 1.49598 \times 10^{11}$ m
Radius of the Earth $R_E = 6.371 \times 10^6$ m
Radius of the Sun $R_S = 6.96 \times 10^8$ m
Mass of the Earth $5.97 \times 10^{24}$ kg
Mass of the Sun $1.99 \times 10^{30}$ kg
$H_2$ Molar mass 2.016 g/mol
$O_2$ Molar mass 31.998 g/mol
$N_2$ Molar mass 28.013 g/mol

## Section A

1) A bullet hits a moving block of wood, which was thrown up in the air as a target. The bullet stays in it. Which has a bigger change of momentum?

a) The bullet

b) The wood

c) They are both the same

d) The answer depends on the angle of initial velocities

e) The answer depends on the final velocity

2) Tom is riding a hot air balloon by himself. There is a rope ladder hanging from the top of the balloon and reaching into the basket. At a moment when the balloon is stationary in the air, Tom begins climbing the ladder with speed $s$ relative to the ladder. Suppose Tom has mass $m$, the balloon has mass $M$. What is the speed of the balloon relative to the ground if air resistance can be neglected?

a) $s$

b) $\frac{m}{M}s$

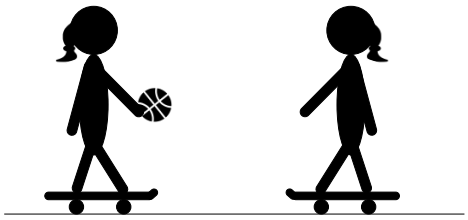
c) $\frac{m}{M+m}s$

d) $\sqrt{\frac{m}{M+m}}s$

e) 0

3) Ann and Betty are good at throwing and catching balls. They can always throw a ball for the other to catch it with only negligible motion. This time they want to have more fun and play the game on skateboards as shown. Initially they are both at rest. Ann first throws the ball to Betty at speed u. After catching the ball, Betty throws the ball back to Ann at the same speed. After Ann catches the ball, Betty is moving faster than Ann by how much? Assuming

mass of the ball = m
mass of Ann and the skateboard = mass of Betty and the skateboard = M



a) $\frac{Mm+2m^2}{M(M+m)}u$

b) $\frac{2m^2}{M(M+m)}u$

c) $\frac{2m}{M+m}u$

d) $-\frac{2m}{M+m}u$

e) $\frac{m}{M}u$

4) Two objects are lying at rest on a flat, smooth surface. Suppose the mass of object $B$ is twice that of object $A$. If the same horizontal force is applied to the objects for the same length of time, what is the ratio of energy gain of object A to that of B?

a) 1:4

b) 1:2

c) 1:1

d) 2:1

e) 4:1

5) Air resistance affects a satellite orbiting the Earth in a nearly circular orbit. Which of the followings does not occur?

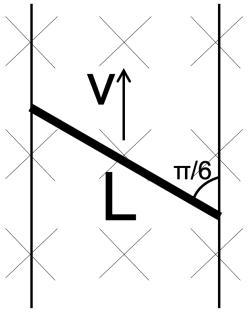
a) An increase in the time for the satellite to complete one revolution

b) A decrease in the total mechanical energy

c) An increase in the linear speed

d) A decrease in the distance to the Earth

6) A metal rod of length L is inclined on the rails in a uniform magnetic field of flux density B as shown in the graph. If the rod moves with constant velocity v upward, what is the induced emf on the rod?



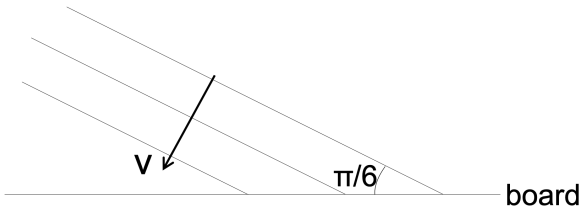

a) $\frac{2BLv}{\sqrt{3}}$

b) $\frac{\sqrt{3}BLv}{2}$

c) $BLv$

d) $\frac{BLv}{2}$

7) The graph below is showing the wavefronts of a plane wave with frequency 3 Hz travelling at speed $v = 6$ m/s hitting a board at an angle $\pi/6$. What is the phase difference between the waves at two points 1 m apart along the board?




a) $\frac{\pi}{2}$

b) $\frac{\pi}{3}$

c) $\frac{\pi}{4}$

d) $\frac{\pi}{6}$

8) A uniform wire of cross-sectional area 1 mm$^2$ has resistance 3 Ω. A voltage difference of 6 V is applied across its two ends. Given that the number of conduction electron per volume of the wire is $1.00\times10^{28}$ m$^{-3}$, what is the average velocity of electron along the wire?

a) 3x10$^8$ m/s

b) 3.1x10$^{-3}$ m/s

c) 3.1x10$^{-4}$ m/s

d) 1.3x10$^{-3}$ m/s

e) 1.3x10$^{-4}$ m/s

9) Two metal balls of the same diameter but different mass are dropped simultaneously from a high cliff . Which of the statements below describes best what happens?

a) The heavier one has the same acceleration from the start

b) The lighter one has higher acceleration from the start

c) They both have the same acceleration at the start but then the lighter one has higher acceleration.

d) They both have the same acceleration at the start but then the heavier one has higher acceleration.

e) They both have the acceleration all the way to the bottom

10) A person biking down a 5° slope without pedaling or braking noticed that her speed is constant at 25 km/h. Approximately what power does she need to bike up this hill at the same speed if her weight including the bike is 65 kg?

a) Nobody can bike down the hill at constant speed without braking.

b) 800 W

c) 1400 W

d) 400 W

e) 2800 W

11) A level (a device for establishing a horizontal plane, which consists of a small sealed transparent tube containing liquid and an air bubble) was pushed on the table. When the level was accelerated, the bubble:

a) did not move relative to the glass

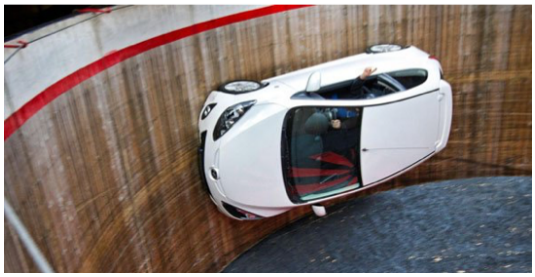
b) moved in the direction of acceleration

c) moved in the direction opposite to the acceleration

d) moved to the side of the tube

e) was pushed deeper into the liquid

12) People were watching a movie showing a car driving inside a big cylinder on a vertical wall (see below a frame from this video obtained from www.aol.co.uk/2012/04/05). How would you explain this?



a) Impossible – some kind of film trick

b) The only way to do it would be to add some very strong magnets in the wheels and drive on iron wall. The attraction force between the magnets and the iron wall results in the friction force to be bigger than the force of gravity pushing the car down.

c) Most likely, there is a huge vacuum pump under the car, which sucks it to the wall and results in a friction force bigger than the force of gravity pushing the car down.

d) The car is moving at high speed so a centripetal force forcing it to drive in circle inside the cylinder results in the force pushing the car towards the wall. This force results in the friction force bigger than the force of gravity pushing the car down.

13) A diver shines a beam of light from a laser at 80° to the surface as shown below. How high above the water surface will the laser beam hit the vertical wall placed 2 m away from the point A (the place where the laser beam hits the surface of the water)?

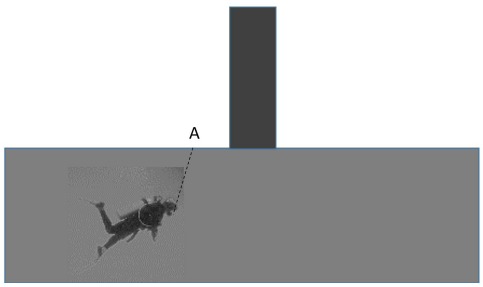
a) About 15m

b) About 8 m

c) About 2 m

d) About 0.2 m

e) It will never go above the water



14) If he directs the beam (from the previous question) to be 20° to the surface, how high above the water surface will the laser beam hit the vertical wall placed 2 m away from the point A (the place where the laser beam hits the surface of the water)?

a) About 15m

b) About 8 m

c) About 2 m

d) About 0.2 m

e) It will never go above the water

15) We are using X-rays (the wavelength of the order of 0.1 nm) to measure the spacing between the atoms or molecules in crystals. If we use a beam of neutrons for the same purpose their energy should be of the order of:

a) $10^{-15}$J

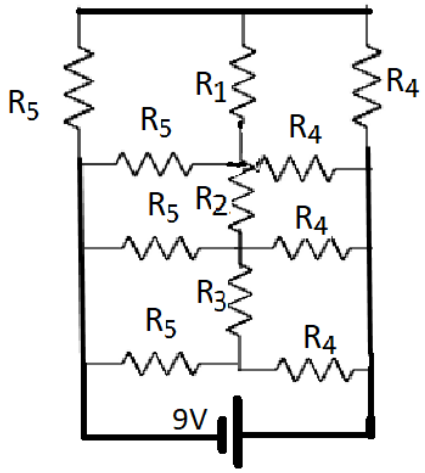
b) $10^{-10}$J

c) $10^{-20}$J

d) $10^{-5}$J

e) $10^{-25}$J

16) What is the voltage across the resistor $R_1$ in the circuit below?




a) $(9R_5/(R_5+R_4))*R_1/(R_1+R_2+R3)$

b) $(9R_4/(R_5+R_4))*R_1/(R_1+R_2+R_3)$

c) 0

d) $9R_1/(R_1+R_2+R_3)$

e) $(36R_4/(R_5+R_4))*R_1/(R_1+R_2+R_3)$

17) A child sitting on an inflatable mattress in the swimming pool had a 20 kg steel weight with him. When he dropped it to the bottom of the pool the water level in the pool:

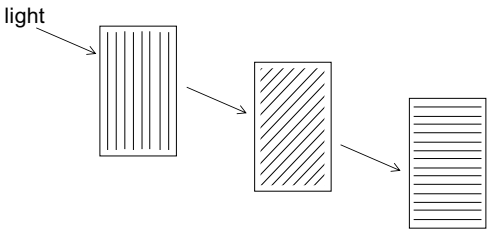
a) Went down

b) Went up

c) Did not change

d) Depends on the mass of the child and mattress

18) A polarizer is a device that lets the component of light parallel to the polarizer's direction to go through and absorb the perpendicular direction. For example, a vertically oriented polarizer only allows the vertical component of the light to go through and the transmitted light is a vertically polarized light. Now we have three polarizers as shown below. The first polarizer is vertically oriented and the last one is horizontally oriented. The middle one is oriented at an angle $\theta$ with respect to the vertical direction. When a randomly oriented light with intensity L is passed into this series of polarizer, what is the intensity of the light after it passes through the third polarizer?




a) 0

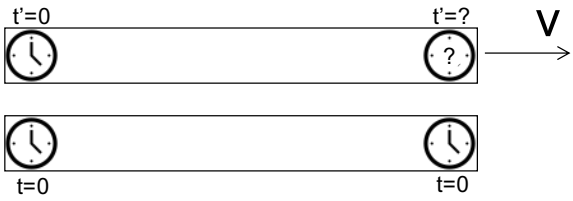
b) L/8

c) L/4cos$^2\theta$

d) L/2cos$\theta$sin$\theta$

e) L/2cos$^2\theta$sin$^2\theta$

19) The figure below shows two rectangular spaceships, one at rest and the other one moving at speed $v = \sqrt{3}c/2$. In the stationary frame, they are seen to have the same length $L$ and their two ends align at $t = 0$. If we know that the clock at the left end of the moving spaceship is showing that the time is at $t' = 0$, what time would the clock at its right end show?




a) $-\sqrt{3}L/c$

b) $\sqrt{3}L/c$

c) $-L/\sqrt{3}c$

d) $L/\sqrt{3}c$

e) 0

20) A car has maximum acceleration of $a$ and maximum deceleration of $-a$. The shortest possible time for the car to begin at rest, then arrive at rest at a point a distance $\Delta$x away is

a) $\sqrt{\frac{\Delta x}{2a}}$

b) $\sqrt{\frac{4\Delta x}{a}}$

c) $\sqrt{\frac{2\Delta x}{a}}$

d) $\sqrt{\frac{3\Delta x}{2a}}$

e) $\sqrt{\frac{\Delta x}{a}}$

21) A uniform spring is fixed at one end. A mass is attached to the other end and the system oscillates with angular frequency $\omega$. Now suppose the spring is fixed at both ends, then cut in half and the mass is attached between the two half springs. The new angular frequency of oscillations is:

a) $\omega/2$

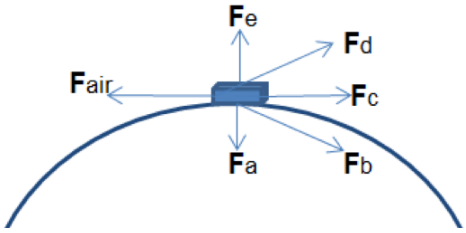
b) $2\omega$

c) $4\omega$

d) $\omega$

e) $\sqrt{2}\omega$

22) A car travels with constant speed on a circular road on level ground as shown below. $F_{air}$ is the force of air resistance on the car. Which of the other force is the horizontal force of the road on the car's tires?




a) $F_a$

b) $F_b$

c) $F_c$

d) $F_d$

e) $F_e$

23) What is the speed of a particle observed to have a momentum of 5 MeV/c and a total relativistic energy of 10 MeV?

a) c

b) 0.75 c

c) 0.5 c

d) c/$\sqrt{3}$

e) 0.25 c

24) Cherie is doing an experiment; she needs to heat a small sample to 700 K. There is only one oven available with a maximum temperature of 400 K. Could she heat the sample to 700 K by using a large lens to focus the radiation from the oven onto the sample?

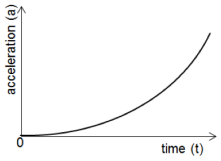
a) Yes, if the volume of the oven is at least 7/4 the volume of the sample.

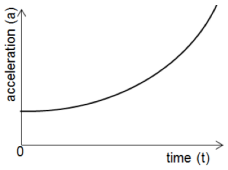
b) Yes, if the area of the front of the oven is at least 7/4 the area of the front of the sample.

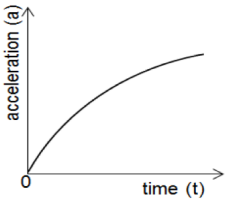
c) Yes, if the sample is placed at the focal point of the lens.

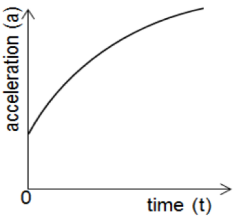
d) No, because it would violate the conservation of energy.

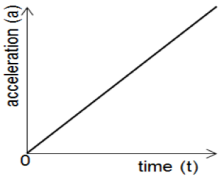
e) No, because it would violate the second law of thermodynamics.

a)


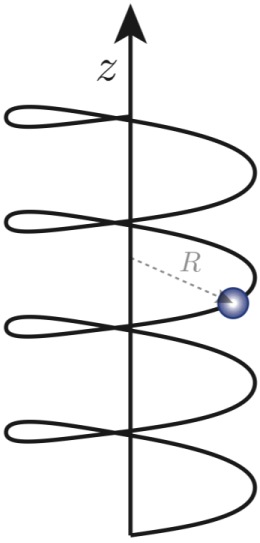

b)



c)



d)



e)



25)




A bead slides on a wire with the shape of a helix as shown above, whose symmetry axis is oriented vertically. Which graph on the right best represents the acceleration of the bead as a function of time?

## End of Section A

## Section B starts on next page

1) The velocity needed for the rocket or other projectile to orbit around the Earth is called the 'first cosmic velocity' ($v_1$). The velocity required to escape the Earth is called the 'second cosmic velocity' ($v_2$). The minimum velocity has to attain to leave the solar system from the Earth is called the 'third cosmic velocity' ($v_3$). In terms of the radius of the Earth $R$, the speed Earth orbiting around the Sun $v$ and the gravitational acceleration near the Earth surface $g$, find

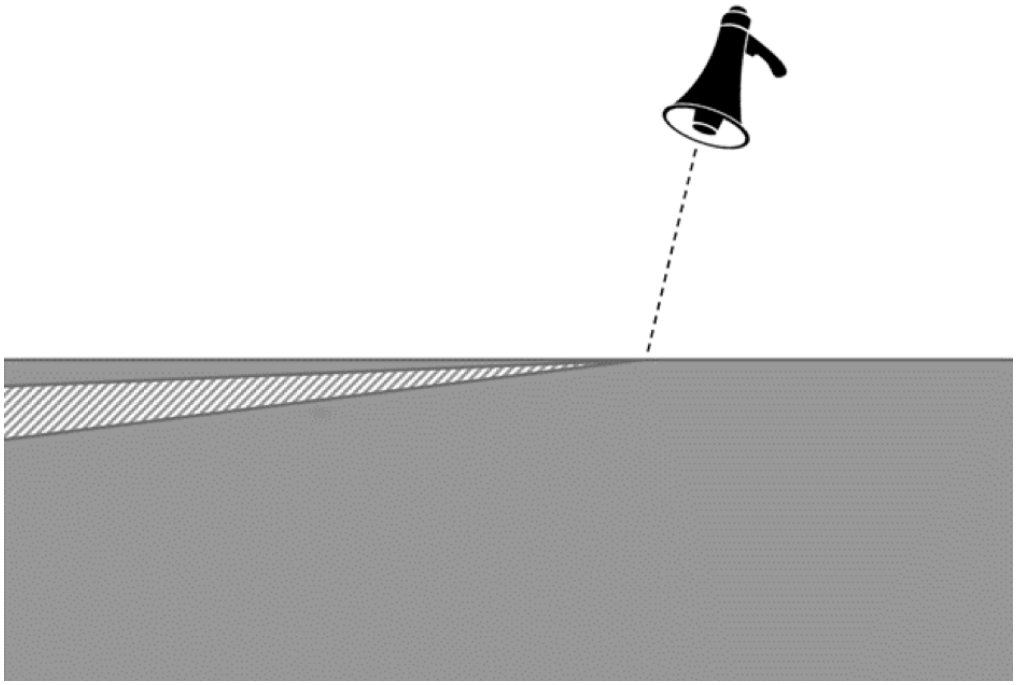
a) The 'first cosmic velocity' ($v_1$)

b) The 'second cosmic velocity' ($v_2$)

c) The 'third cosmic velocity' ($v_3$)

Finally, estimate the values of $v_1$, $v_2$ and $v_3$ using values from the formula page and the expressions obtained above.

2) A very narrow beam of sound from a directional loudspeaker was directed towards the water at the angle 77° to the surface as shown by a dashed line on the picture. It was noticed that the fish avoids the dashed area, as they dislike the noise. Using the information from the picture calculate the speed of sound in water.



3) Deuterium is the heavy stable isotope of hydrogen, having a proton and neutron in its nucleus (protons and neutrons have approximately the same mass). Heavy water is a form of water that contains Deuterium and Oxygen. A heavy water nuclear reactor has heavy water between the nuclear fuel rods. Suppose that a neutron from the fuel rod has a head-on elastic collision with a Dueterium nucleus.

a) Find the ratio of the final speed of the deuteron to the initial speed of the neutron.

b) What percentage of the initial kinetic energy is transferred to the deuteron?

c) How many such collisions is needed to slow down the neutron from 20 MeV to 0.02 eV?

d) How would this estimate change if we consider collisions at other angles?

| | | | | | | |
|---|---|---|---|---|---|---|
| Question 1 | a | b | c | d | e | f |
| Question 2 | a | b | c | d | e | f |
| Question 3 | a | b | c | d | e | f |
| Question 4 | a | b | c | d | e | f |
| Question 5 | a | b | c | d | e | f |
| Question 6 | a | b | c | d | e | f |
| Question 7 | a | b | c | d | e | f |
| Question 8 | a | b | c | d | e | f |
| Question 9 | a | b | c | d | e | f |
| Question 10 | a | b | c | d | e | f |
| Question 11 | a | b | c | d | e | f |
| Question 12 | a | b | c | d | e | f |
| Question 13 | a | b | c | d | e | f |
| Question 14 | a | b | c | d | e | f |
| Question 15 | a | b | c | d | e | f |
| Question 16 | a | b | c | d | e | f |
| Question 17 | a | b | c | d | e | f |
| Question 18 | a | b | c | d | e | f |
| Question 19 | a | b | c | d | e | f |
| Question 20 | a | b | c | d | e | f |
| Question 21 | a | b | c | d | e | f |
| Question 22 | a | b | c | d | e | f |
| Question 23 | a | b | c | d | e | f |
| Question 24 | a | b | c | d | e | f |
| Question 25 | a | b | c | d | e | f |