U3A Science Group - Christmas Quiz Answers

Q1: The Rainford Bypass between Ormskirk and St Helens in places runs 4 feet above the surrounding fields. Why?

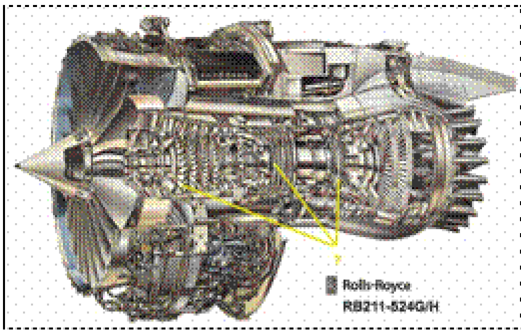
Answer: In fact the bypass doesn't run 4 feet above the fields, the fields run 4 feet below the road! This is because the bypass was quite an early construction of its type, built in the early 1930s and sand was extracted from below the surrounding fields to feed the Pilkington sheet glass works in St Helens from 1937 until the early 1960s. The process was to remove the top soil, extract the sand from below it and replace the top soil. The result of this was the field levels fell below the level of the bypass.

Q2: If Grand Central Station in New York were a nuclear power station it would be closed down. Why?

Answer: Grand Central Station is constructed largely of granite; the natural uranium content of granite makes it mildly radioactive. The travelling public who use Grand Central therefore are irradiated continually by their surroundings as they pass through. Regulations for nuclear power stations are set such that they limit the exposure of the general public to radiation at a lower level than the experienced by using Grand Central.

Q3: The Rolls Royce Trent aero engine has a rubber tip to the cone at the centre of its air input fan. Why?

Answer: Nothing to do with bird strikes! Moist air sucked in by the turbofan rapidly cools as the pressure decreases; ice then can form on the fan blades and the cone. The ice cannot stick to the blades because of centrifugal forces but it can stick to the tip of the cone, form larger lumps which eventually crack off and enter the engine causing blade damage. The trick is to have a rubber tip on the cone which wobbles a little during flight and thereby inhibits ice sticking to the point. Problem solved!



Q4: The emperor of China wished to reward the inventor of the game of chess. The inventor requested a grain of rice for the first square of the chess board, double for the second (two grains), doubled again for the third (four grains), doubled again for the fourth (eight grains) etc. The emperor granted his request readily. Was this a good idea?

Answer: There are 68 squares on a chess board (8 by 8). The total number of grains of rice is therefore:

$$T_{64} = 1 + 2 + 4 + \cdots + 2^{63} = \sum_{i=0}^{63} 2^i = 2^{64} - 1$$

$2^{64}-1$ = 18,446,744,073,709,551,615 grains of rice (18 million trillion ish). With one grain of rice weighing about 25 mg this gives you a pile of rice weighing 461,168,602,000 tons, somewhat larger than Mount Everest.

Beware exponential growth, your credit card debts can grow like the Emperor of China's pile of rice!

Q5: You can rotate your right leg and right arm simultaneously in a clockwise direction. Can you rotate your right leg clockwise and your right arm anticlockwise?

Answer: Have you tried this at home (with no one watching)? Generally you can rotate your right leg and right arm (or left leg and left arm) together in the same direction. In the trade the limbs are said to be coupled in iso-directional oscillations. Right leg and left arm (or left leg and right arm) rotation is another matter: this is called anti-directional coupling and is generally impossible. Nobody seems to be sure why – so this question doesn't seem to have an answer. Unless you know better!

Q6: You flip a coin three times and it comes up heads every time. What is the likelihood if it coming up heads for the fourth time?

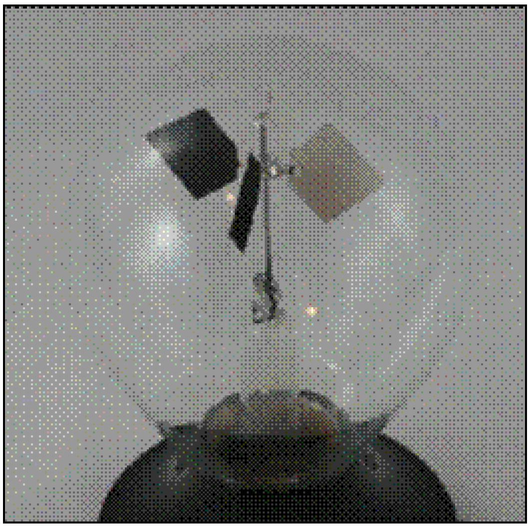
Answer: 50:50 i.e. 1 in 2. Coins do not have a memory. Starting from scratch the chances of getting 3 heads are 1 in $2 \times 2 \times 2 = 1$ in 8. The next coin flip gives you another 1in 2 chance so from scratch the chances of getting 4 heads is (1 in 8) × (1 in 2) i.e. 1 in 16. It all depends at which point you ask the question: before flipping any coins or after achieving the slightly unlikely 3 heads outcome and wanting to know how likely it is that you might move on to the more unlikely 4 heads outcome.

Q7: You are in a lift with your budgerigar in a cage, the budgerigar is flying around the cage. The lift cable breaks and the lift cabin hurtles towards the ground; however you are clever and jump in the air just before the lift hits the ground so that you fall gently to the floor while the fluttering budgerigar gentle settles on your shoulder. Is that what happens?

Answer: No it isn't. Initially the lift cable is holding the lift, and via the pressure on your feet, you, against the pull of gravity. The budgerigar isn't held up by the lift cable; he stays in flight via pushing air down with his wings to get a reaction via Newton's second law of motion pushing him up to balance the force of gravity. When the cable breaks the lift, budgerigar cage and you are unsupported and fall under gravity, the budgerigar maintains his height relative to the earth but unfortunately is met by the falling roof of his cage which is freely falling with the following result:

When the lift finally nears the ground it, and you, will be travelling at high speed "downwards" due to accelerating under gravity during its fall. If you jump "up" as the lift nears the ground your jump velocity will be subtracted from your previous downwards velocity however your "up" velocity will be small compared with your "down" velocity and your net velocity will be downwards: this you will experience when you hit the floor of the lift shortly after it hits the ground and you end up like the budgerigar.

Q8: The Crookes radiometer comprised vanes on a freely rotating paddle wheel in a vacuum. One side of the vanes are silvered and the other side blackened.
When light shines on the radiometer the wheel rotates due to light pressure; photons bouncing off the silvered side of the paddles pushing the wheel around; or at least that is the conventional explanation. What's wrong with it?

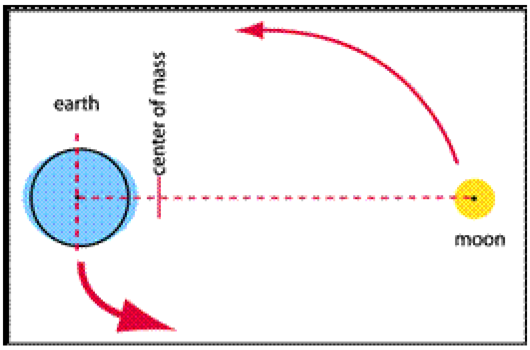


Answer: This device was invented by the chemist, Sir William Crookes, in 1873 who discovered the effect as a by- product of some chemical work on very accurate quantitative analytical weighing. He attributed the motion to light pressure and was supported in the explanation by the famous physicist James Clerk Maxwell. Unfortunately it was not until 1876 that Schuster, another physicist, noticed that the vanes were rotating in the opposite direction to that expected! It is now known that the light pressure is too small to rotate the vane against the small amount of friction in its pivot. The rotation is due to the blackened side of the vanes being slightly warmer than the silvered side due to absorption of heat radiation, residual air molecules in the less than perfect vacuum colliding with the vanes surfaces therefore leave the blackened surfaces at a higher velocity than the silvered surfaces resulting in rotation of the paddle in the "black to silver" direction. You can see this in action using infrared radiation at

http://www.youtube.com/watch?v=MbdPgc7e0R0

Q9: Tides are caused by the gravitational attraction of the water in the oceans to the moon, as the earth rotates once a day a tidal ocean wave sweeps around the earth. OK, but why are there two tides a day rather than one?

Answer: It is a bit simplistic to think of the earth as being stationary (relative to the moon) and the moon rotating around the stationary earth, in fact the earth is gravitationally attracted to the moon as well as the moon to the earth. They both rotate around their joint centre of mass so that their joint gravitational attraction is balanced by their centrifugal orbital forces as shown below



This balance of gravitational and centrifugal forces is only perfect at the centre of the earth (and the centre of the moon), along the line joining the centre of the earth and the centre of the moon the closer you get to the centre of mass the more gravitational forces predominate and the further away you get the more the centrifugal forces dominate. The net force is therefore non uniform and the earth tries to distort into an elliptical shape under these forces. The solid part of the earth is limited in how much it can distort but the liquid part can so you have a water lobe towards the moon where gravitational attraction dominates and a second lobe away from the moon where centrifugal forces dominate. As the earth and moon rotate around their joint centre of mass once per day two water lobes (high tides) sweep past any fixed position on the earth.

Q10: The north pole of a compass needle points to the north (of course) because that is where the magnetic north pole is: but north poles of magnets are supposed to be attracted to south poles of magnets and repelled from north poles. Is our compass needle pointing the wrong way?

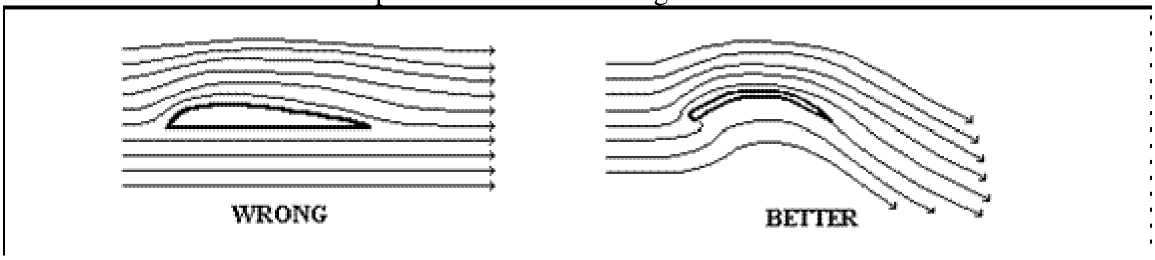
Answer: The north pole of a magnetic compass needle should more properly be called a "north seeking pole" in that it seeks the Earth's Magnetic North Pole. Because opposite poles attract this makes the Earth's Magnetic North Pole, by definition, a magnetic field south pole! Unfortunately in the early days of magnetic science when the poles of a magnet could have been simply labelled + and –, or A and B it was decided to label them north seeking and south seeking based on the earlier use of magnets in compasses. The labelling north and south was quite nominal, unfortunately geography and magnetic theory chose opposite nominal labels which clash in this example.

Q11: When a space craft re-enters the earth's atmosphere it heats up due to friction with the air. Why were the Apollo re-entry capsules so blunt, wouldn't it have been a good idea to make them streamlined to reduce the friction?

Answer: There are two problems with a streamlined re-entry vehicle: firstly it is not very good at slowing down and if you are coming back from the moon there is a danger that you will just "skip" through the earth's atmosphere and shoot off into space instead of landing and secondly the frictional heating of the air you get even with a streamlined re-entry vehicle heats up the vehicle skin rapidly. (You even get some of this effect with Concorde!).
Blunt re-entry vehicles cause a shock wave which push the frictionally-heated air away from the re-entry vehicle where it radiates most of its heat into space rather than conductively heating the vehicle structure. The heat transfer which does occur is taken care of by an ablative coating on the vehicle which produce a gas shield which again protects against excessive heating.

Q12: Aircraft wings have special aerofoil shapes so that the air flowing over the top surface of the wing has further to go than over the bottom surface before it joins up with the flow again at the bottom surface of the wing.
The reduced air pressure on the top surface gives the lift to keep the aircraft aloft. OK, but why can aerobatic aircraft fly upside down?

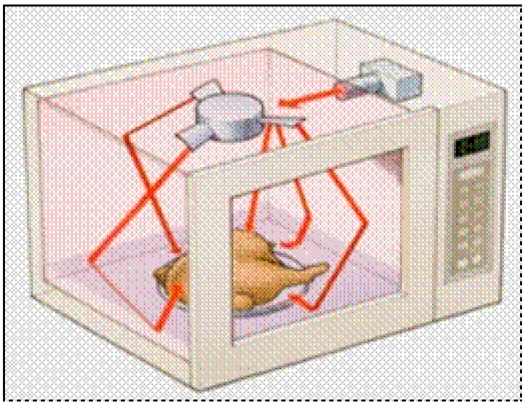
Answer: Aerofoil wings are often show as the first diagram (wrong), there is no "joining up of the airflow". A better representation is shown in the second diagram where the airflow over the wing is deflected downwards and Newton's Second Law of Motion gives a reaction to the downward airflow which is an upward thrust on the wing.



This is what happens when an aircraft is flying forward with the wind pointing directly into the direction of airflow i.e. the so called angle of attack is zero. If the aircraft flies at an angle to the airflow i.e. at a higher angle of attack there is more deflected downflow and hence more lift. Aerobatic aircraft can maintain lift even when flying upside down by increasing their angle of attack to overcome the reverse effect of the aerofoil. Some aerobatic aircraft even have symmetrical wings with no aerofoil shape. This makes it more difficult to fly the normal way up as they have to fly at more of an angle to maintain lift but easier to fly upside down.

Q13: Microwave ovens often have a rotating fan in the top of the oven. As the air in the oven isn't heated and doesn't need a fan to circulate it uniformly what is the purpose of a fan?

Answer: The fan in fact isn't a fan, technically it is known as a mode stirrer. The microwave oven uses microwaves at a frequency of 2.45 GHz (wavelength 12.2 cm) which are absorbed by the food which is thereby heated. Because the wavelength of the radiation is comparable to the dimensions of the oven, reflection of the waves by the oven walls can lead to hot (and cold) spots as the reflected waves reinforce or cancel one another out. The radiation pattern from reflection from the mode stirrer blades continually changes so that the hot and cold spots are evened out with time.



Additionally a rotating turntable is often used to increase the uniformity of heating by moving the food through the radiation pattern.

Q14: What is odd about this clock?

Answer: The clock may look as though it has an hour hand, minute hand and second hand but of course large clocks such as this one on the Bristol Exchange building would not have a second hand - in fact it has two minute hands!

Why does it have two minute hands?

Until the latter part of the 18th century, time was normally determined in each town by reference to a local sundial, because of differences in longitude however there were small differences between the local time of two neighbouring towns and over longer distances with the major cities. For example, in Britain, local times for London, Birmingham, Bristol and Manchester could differ by as much as 16 to 20 minutes. Before the arrival of the railway, journeys would take many hours and as such these differences could be dealt with by adjusting the hands of the watch. It soon became apparent with the arrival of the higher speed railways however that such discrepancies in times caused confusion, disruption or even accidents. By 1855 therefore, railway time was developed where time signals from Greenwich was sent by wireless telegraph alongside the railway lines to synchronise the local time clocks.

The railway companies sometimes faced resistance from local people in a number of places where trains stopped, who refused to agree to adjust their public clocks to bring them into line with London Time. As a consequence two different times would be displayed in the town and that is what you see on the Bristol Exchange clock with one minute hand showing London time 10 minutes ahead of the other hand showing Bristol time. Despite this early reluctance, railway time rapidly became adopted as the default time although it still took until 1880 for the government to legislate on the establishment of a single Standard Time and a single time zone for the country.[3]

Q15: Why is the American standard gauge (width between the rails) of a railway track 4’ 8½’’?

Answer: The most entertaining, explanation on the internet (which has a number of variants) goes like this:

The U.S. standard railroad gauge (distance between the rails) is four feet, eight and a half inches. That's an exceedingly odd number. Why was that gauge used? Because that's the way they built them in England, and English expatriates built the U.S. railroads.
Why did the English people build them like that? Because the first rail lines were built by the same people who built the pre-railroad tramways, and that's the gauge they used.
Why did 'they' use that gauge then? Because the people who built the tramways used the same jigs and tools that they used for building wagons, which used that wheel spacing.
Why did the wagons use that odd wheel spacing? Well, if they tried to use any other spacing the wagons would break on some of the old, long-distance roads, because that's the spacing of the old wheel ruts.
So who built these old rutted roads? The first long-distance roads in Europe were built by Imperial Rome for the benefit of its legions. The roads have been used ever since.
And the ruts? Roman war chariots made the initial ruts, which everyone else had to match for fear of destroying their wagons. Since the chariots were made for or by Imperial Rome, they were all alike in the matter of wheel spacing. Thus, the standard U.S. railroad gauge of four feet, eight and a half inches derives from the specification for an Imperial Roman army war chariot.

This is partly true: although American railway tracks were actually built by American engineers they were built to fit engines manufactured by George Stevenson, the English railway pioneer. His early engines ran on tramway used to haul coal (by horse) in the north of England which used a 4’ 8’’ gauge. The reason for this was that wagons and their wheels averaged five feet in width, since this size would conveniently fit behind a team of draft animals. The tramway gauge apparently had been arrived at by starting with an overall track width of 5’ and using rails that were 2’’ wide. 5’ minus 4’’ for the rails equals 4’ 8’’. Stephenson later widened the tracks a ½’’ for practical reasons, making the standard gauge 4’ 8½’’. But what about Roman war chariots and rutted roads? Roman "rutways", were close to modern railroad tracks in width e.g. the rutways at the buried cities of Pompeii and Herculaneum averaged 4’ 9’’ centre to centre, with a gauge of approximately 4’ 6’’.

My summer holiday snaps of Pompeii show it all!

But there is probably no direct connection between Roman rutways and 18th-century tramways. The designers of each were dealing with a similar problem, namely hauling wheeled vehicles behind draft animals. So it's not too surprising they came up with similar results.

Q16: Without Albert Einstein your satnav would get you lost. Why?

Answer: Your "satnav" is technically a GPS (Global Positioning Satellite) receiver. The receiver communicates with a number of orbiting satellites and uses the transit time of each communication to calculate the distance to each satellite and thereby the position of the receiver on the earth. Very accurate clocks are needed on each satellite to calculate accurately the transit time as the satellite signals propagate at the speed of light and a small clock error leads to a large calculated positional error.

Einstein's *Special* Theory of Relativity predicts that for clocks in relative motion time runs at different rates; the effect is very small and generally only significant when the relative motion of the bodies approaches the speed of light. The satellites are moving relatively slowly (4 km/sec) but Special Relativity predicts that atomic clocks moving at orbital speed tick more slowly than stationary ground clocks by about 7 μs/day. Additionally Einstein's *General* Theory of Relativity predicts that clocks in higher gravitational fields run slower. The GPS receivers on the Earth are in a higher gravitational field than on the satellites (being closer to the centre of the Earth) and the satellite clocks therefore run relatively faster by about 46 μs/day. Combining these two effects together gives a time dilation of about 39 μs/day. If corrections are not made for this effect errors of about 10 km/day would accumulate in your position information so you see that without Albert you would be lost.