MULTIPLE CHOICE QUESTIONS – 1 MARK
TRUE/FALSE QUESTIONS – 1 MARK
SHORT WRITTEN ANSWER QUESTIONS – 5 MARKS EACH

Imagine it is sometime in the future, several hundred years from now, and humans are colonising the solar system and other star systems …

1. Roxanne Stone, well known geologist, has just returned to Earth from a stint on Mars as a planetary geologist although she prefers the term areologist. Areology, the study of Mars, is planetary geology plus everything else that makes Mars what it is: a rocky planet with some Earth-like and some not so Earth-like characteristics. When asked by keen news reporter, Nigel Oatworthy, what she missed most about Earth she said:

   … until the Martian Congressional Republic successfully terraforms the planet, everybody from Earth will miss nearly everything that makes Earth not Mars.

   When pressed for a specific example she replied:

   … not being able to go outside without a suit because the air pressure and temperature are so low and the atmosphere contains no oxygen. The super fine wind-blown dust gets into everything and you cannot enjoy a swim in the open or visit a beach but I never got used to the sky. I missed the blue sky.

   Nigel had never thought about why the sky was blue or if Mars had the same coloured sky. He immediately asked Roxanne to explain why Mars has a different coloured sky.

Q: What did Roxanne say to the reporter to explain the difference between the Martian sky and Earth's sky?

a. Earth's atmosphere contains gas molecules that scatter blue light better than other colours so the sky is blue whereas on Mars the thick dense atmosphere contains molecules that scatter red light more effectively so the Martian sky is red.
b. Earth's atmosphere contains gas molecules that scatter blue light better than other colours so the sky is blue whereas on Mars the thin atmosphere contains gasses that scatter all colours equally that add together to make the Martian sky red.
c. Earth's atmosphere contains gas molecules that scatter blue light better than other colours so the sky is blue whereas on Mars the thin atmosphere contains iron oxide dust that adsorbs blue light and scatters red light so the Martian sky is red.
d. Earth's atmosphere contains gas molecules that scatter blue light better than other colours so the sky is blue but Mars has such a thin dust-free atmosphere that the sky is black.
e. Earth's atmosphere contains gas molecules that scatter blue light better than other colours so the sky is blue. It is the same on Mars but the temperature of the air is so low only warm red light can travel through the entire atmosphere so Mars looks red.
f. I'm joking! There is no reason why the sky would be different because all gasses scatter light in exactly the same way …but the gravity … Don't get me started about the gravity!

2. Roxanne also commented to Nigel and the other reporters greeting her upon landing at the space port that the gravity on Mars made it hard to adjust to living there and then to re-adjust to living on Earth after a prolonged visit to Mars. A reporter, who had never been off planet (not even for a quick lunar holiday made affordable by the space elevator), wanted to know what the problem was with gravity on Mars. She explained that Martian gravity is only about one third that of Earth's gravity (0.376 g actually) so a person with a mass of 100 kg who weighs about 980 Newton on Earth only weighs about 370 Newton on Mars.

   Q: The reporter tested Roxanne's patience by asking why there was a difference. What did Roxanne reply?

   a. … Mars is further from the Sun than the Earth so has less gravity.
   b. … Mars has two tiny moons so has less gravity than Earth with its one big moon.
   c. … Mars is closer to Jupiter than Earth so some of the Sun's gravity is cancelled out by Jupiter's gravity resulting in Mars having less gravity than Earth.
   d. … Mars has a mass / radius ratio smaller than Earth's so has less gravity.
   e. … compared with Earth, Mars has a thinner atmosphere so has less gravity.
   f. … Mars has a circular orbit so it has less centripetal force and therefore does not have as much apparent gravity as Earth that has a more elliptical orbit.

Roxanne caught up with her siblings, Gemma and Orson, a short car flight from the space port. Gemma had just returned from the Moon. Working on the Moon, she had been exploring the magnetic anomalies proximal to Tycho Crater. Roxanne was keen to catch up and find out more about the Moon too. Gemma showed Roxanne a souvenir hologram of Tycho Crater she picked up luna-side (Figure 1). Distinct radial lines - also known as rays - focussed on several craters including Tycho and Copernicus, are clearly visible as is the 21st century version of the International Space Station (ISS). The image, captured way back in 2015, is a favourite of lunar enthusiasts who like to admire the Moon in its pristine pre-settlement appearance.

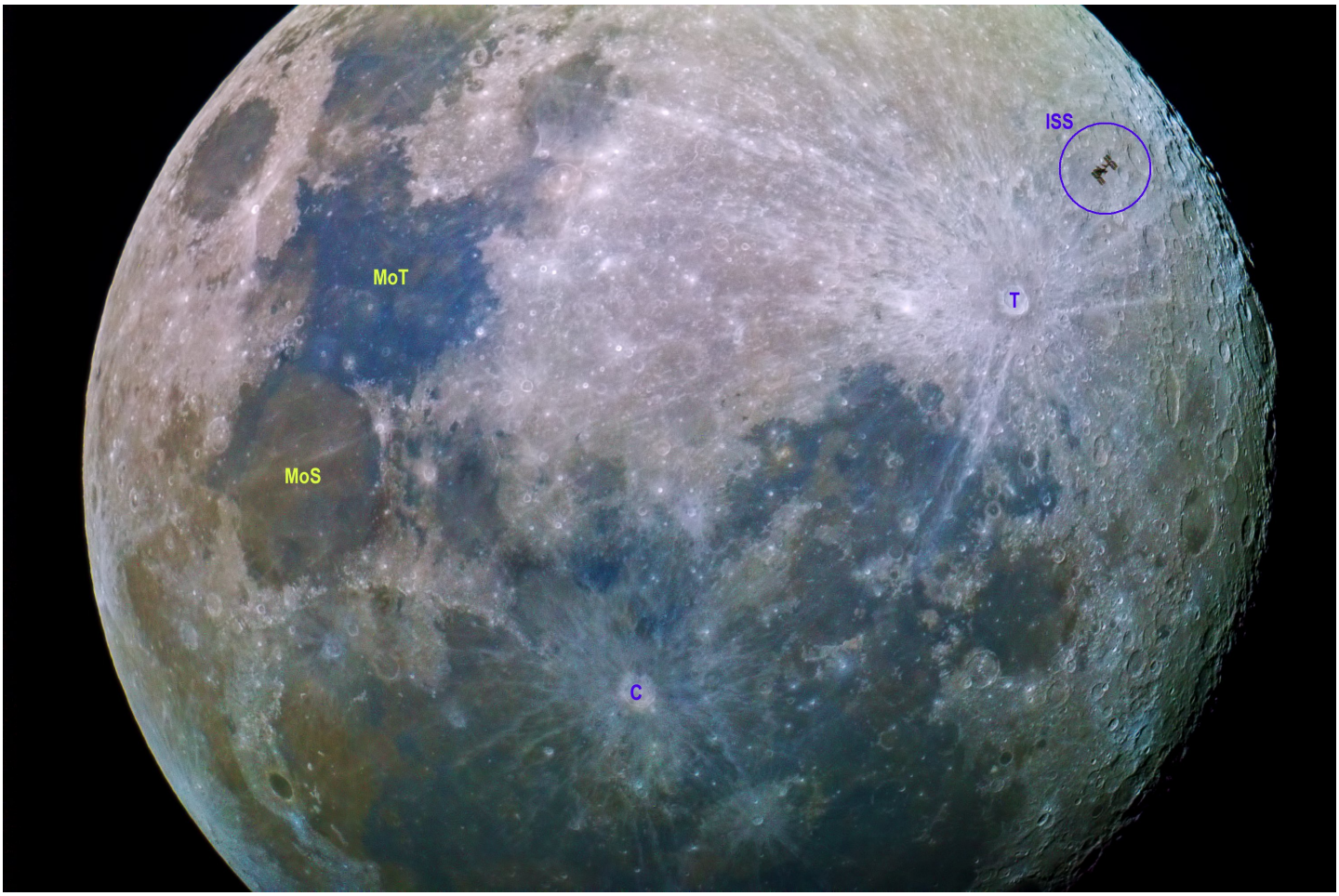

Figure 1: International Space Station (ISS) silhouetted against the Moon with Tycho Crater (T) top right and Copernicus Crater (C) centre bottom. Also labelled are the low lying basalt plains known as Mare Tranquillitatis (MoT) and Mare Serenitatis (MoS). Public Domain image captured by Dylan O'Donnell 1 July 2015 from Byron Bay Australia. https://tinyurl.com/p8f96s3

3. Gemma and Roxanne have a healthy sisterly rivalry, so she had to throw Roxanne a challenge. A quick look at the archives revealed the 2015 ISS orbited Earth at an average altitude of 409 km and an orbital speed of 7.66 km/s. Consulting her Don't Panic Guide to Everything, Gemma confirmed the Moon has a diameter of 3,474.8 km and an average surface to surface distance of 376,285 km. Given this background information, Gemma asked her sister:

   How many seconds did the photographer have to snap an image that included the ISS in silhouette against the face of the Moon somewhere (disregarding any motions of the Earth and Moon) assuming the ISS transited across the Moon a distance equivalent to 75% of the Moon's full diameter?

   Q: What correct answer did Roxanne suggest after a bit of quick thinking?

   a. More than 15 seconds
   b. Between 10 and 15 seconds
   c. Between 5 and 10 seconds
   d. Between 1 and 5 seconds
   e. Between 0.5 and 1 second
   f. Between 0.1 and 0.5 of a second

4. The colours in the image of the Moon (Figure 1) are real, albeit enhanced by the photographic technique to make them more visible to the human eye. The colours also correlate with different geological terrains on the surface of the Moon. Gemma said that generally very light-coloured features are younger than dark coloured features and that Tycho Crater was one of the youngest large craters anywhere on the near-side of the Moon, something that scientists have known since the 20th century.

   Roxanne was curious about the age of Tycho Crater and asked Gemma how 20th century scientists could have known the relative age of the material given there were no bases on the Moon then.

   Q: What was Gemma's answer?

   a. The rays from Tycho Crater are impact ejecta caused by a large crater forming impact. They have been mapped using Earth-based telescopes and overlie most other features.
   b. The rays from Tycho Crater are impact ejecta caused by crater a large forming impact. They have been mapped using Earth-based telescopes and underlie most other features.
   c. The rays from Tycho Crater are a radial dyke swarm centred on a very ancient volcano, formed on the early surface of the Moon, that was coincidently hit by an asteroid – forming Tycho Crater - much more recently.
   d. On Earth the oldest rocks are always a lighter colour than the younger rocks so, using the principle of uniformitarianism, the same applies to the Moon too.
   e. On Earth the youngest rocks are always a lighter colour than the older rocks so, using the principle of uniformitarianism, the same applies to the Moon too.
   f. They didn't really know, it was just guess work.

Roxanne knew that the Apollo lunar missions that landed on the Moon (1969 – 1972) brought back lots of samples to Earth for analysis. However, Apollo 17, the last mission sent back 110 kg of rock and was also special because one of the crew – Harrison Schmitt - was a geoscientist. The Apollo 17 site is now a popular geo-tourism site, especially amongst visiting geoscientists such as Gemma. Gemma told Roxanne that she had the privilege of visiting the site as part of a post-conference field trip, seeing the collection site of one of the rocks and later – in a lab on Earth - confirming the age of that rock collected by Schmitt using an incredibly Sensitive High Resolution Ion Micro Probe (iSHRIMP). She confirmed it was a piece of Tycho ejecta dated at 108 ± 0.1 Ma (Ma = millions of years).

5. Roxanne was impressed but palaeontology was not her strong point. She speculated about the animals on Earth that might have actually witnessed the Tycho impact event. Gemma, who always loved collecting and studying fossils with her university friend Rose Kortz, quickly set Roxanne on the right track.

   Q: What major groups of organisms did Gemma confirm would have witnessed this event?

   a. Hominids and Birds
   b. Birds and Dinosaurs
   c. Dinosaurs and Trilobites
   d. Placoderm fish and cyanobacteria
   e. Trilobites and Graptolites
   f. Whales and Hominids

6. Roxanne noted Tycho Crater is 86 km in diameter and has sent ejecta over 2000 km across the surface of the Moon. She suggested to Gemma that such a large impact must have ejected some fragments at lunar escape velocities. She asked Gemma if that was likely.

   Q: What did Gemma say to confirm what happened?

   a. Some ejecta would have been molten. In space this would have quenched to a glass.
   b. Some ejecta would have been still solid (unmelted) fragments.
   c. Some ejecta would have escaped to space and will still be travelling on trajectories that started 108 million years ago.
   d. Some ejecta would have rained down on Earth as meteorites.
   e. Some ejecta may have become meteorites on Mars and other Solar System bodies
   f. All of the above.

The following information relates to questions 7, 8, 9, 10 & 11.

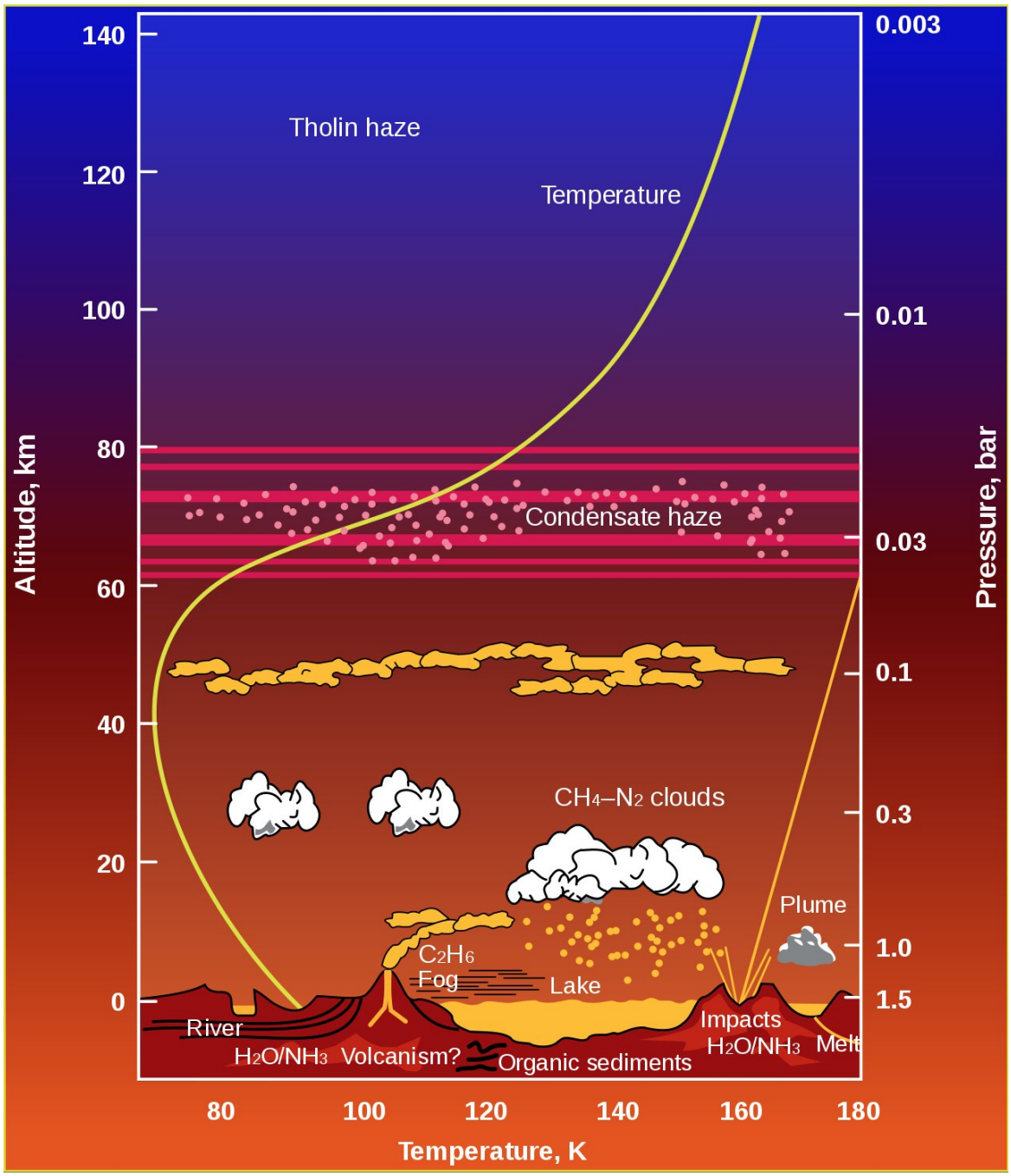

Figure 2: A graph detailing temperature, pressure, and other aspects of Titan's climate.

Note 1: The temperatures on the x-axis relate to the atmospheric profile of the graph and not to the generalised landscape features at the bottom of the image. Image courtesy of NASA. https://tinyurl.com/ycpqk4x9

Note 2: Tholins are a wide variety of organic compounds formed by solar ultraviolet or cosmic ray irradiation of simple carbon-containing compounds such as carbon dioxide (CO_2), methane (CH_4) or ethane (C_2H_6), often in combination with nitrogen (N_2) or water (H_2O). In the presence of water, tholins can be raw materials for prebiotic chemistry.

Note 3: Condensate haze is formed from by photochemical reactions high in the CH_4/N_2 atmosphere generating aerosol particles, which aggregate into fractal agglomerates and generate a thick haze layer.

Roxanne Stone's discovery of fossil-like structures on Mars has made her something of a media celebrity, even though the jury is still out on whether they really are fossils. In one of her interviews, she was asked what she planned to do next. She emphasised that the search for life of any kind beyond Earth was still a work in progress, but now that they could explore the Solar System relatively quickly, thanks to the Epstein Drive, she hoped to return to Jupiter's moons or possibly explore Saturn's moons, especially Titan.

Roxanne explained that Titan is the only place in the Solar System, other than Earth, with a surface environment that facilitates rapid cycling of a compound between solid, liquid and gas phases. It is presumed that a liquid phase is essential for living systems. That compound is water on Earth; on Titan, it is methane. *For methane to behave like this, the surface temperature must hover around negative 180 degrees Celsius (93 K). It might not host life as we know it, but it is still a strong candidate as a home for some form of life,* she added.

7. Gemma watched the interview live online. She sent Roxanne a text that read:

Hi Roxy,
Great interview, but the reporter missed the chance to ask you some good questions!
I read a paper recently that concluded that high reflectivity areas on Titan's equator are dry lake beds. So here is a question: When it rains on Titan where does all the liquid methane go?
CU Gemma

Roxanne initially replied saying:

Titan has a methane cycle, just like Earth's water cycle. When it rains, the liquid methane runs off into streams and lakes. However, the climate and weather systems on Titan are not well understood because on Titan, each of the 4 seasons is about 7 Earth years long, with each day equivalent to about 16 Earth days – the same time it takes Titan to orbit Saturn – and we have not been on site long enough to understand rainfall patterns but …

Q: What else did Roxanne say in return when she sent Gemma this image (Figure 2)?

a. … dry lake beds at the equator mean it never rains on the equator.
b. … dry lake beds indicate surface liquid methane might sometimes evaporate resulting from changes from a wet season to a dry season.
c. … dry lake beds indicate surface liquid methane might sometime infiltrate into subsurface sediments
d. … the dry lake beds indicate any chance of finding life on Titan is long gone
e. She said both b & c.
f. She said all of a, b, c & d.

8. Gemma gave Roxanne a thumbs up for that answer but quickly asked another question:

If Titan orbits Saturn roughly every 16 Earth days why are each of Titan's 4 seasons about 7 Earth years long?

Roxanne initially replied saying:

Titan's orbital tilt with respect to the sun is very close to Saturn's axial tilt (about 27°), and its axial tilt with respect to its orbit is zero. So …

Q: What else did Roxanne say in this reply?

a. … seasonal change is driven by Saturn's year which is about ~29 Earth years long
b. … seasonal change is driven by Saturn's year which is about ~7 Earth years long
c. … seasonal change is driven by Saturn's year which is about ~14 Earth years long
d. … seasonal change is driven by Saturn's year which is about ~58 Earth years long
e. … seasonal change is driven by Saturn's year which is about ~116 Earth years long
f. … seasonal change is driven by Titan's interaction with Saturn's variable gravity that has a change periodicity of ~7 Earth years

9. Gemma sent another question as soon as Roxanne sent her reply. Gemma asked:

> *In the graph you sent (Figure 2), I don't understand why the temperature profile indicates Titan's atmosphere is colder at an altitude of 40 km than at ground level or 140 km. After all, methane is a greenhouse gas and should make the whole atmosphere warmer.*

Q: What did Roxanne say to explain this counter-intuitive graph?

> *Hi Gemstone,*
> *Yes, you are right. Atmospheric methane creates a greenhouse effect on Titan's surface, without which Titan would be far colder, but …*

a. … light reflecting off smooth lake surfaces contributes to an anti-greenhouse effect by reflecting sunlight back into space, negating a portion of the greenhouse effect and making its surface significantly colder than its upper atmosphere.
b. … the haze in Titan's atmosphere, between 60 and 80 km altitude, contributes to an anti-greenhouse effect by reflecting sunlight back into space, negating a portion of the greenhouse effect and making its surface significantly colder than its upper atmosphere.
c. … the formation of CH4-N2 clouds, between 20 and 40 km altitude, contributes to the greenhouse effect by reflecting sunlight back into space, making its surface significantly colder than its upper atmosphere.
d. … the C2H6 clouds in Titan's atmosphere between 40 and 60 km altitude contributes to an anti-greenhouse effect by reflecting sunlight back into space, negating a portion of the greenhouse effect and making its surface significantly colder than its upper atmosphere.
e. … the haze in Titan's atmosphere between 80 and 140 km altitude contributes to an anti-greenhouse effect by reflecting sunlight back into space, negating a portion of the greenhouse effect and making its surface significantly colder than its upper atmosphere.
f. All 5 statements listed here are correct according to Roxanne's explanation.

10. Gemma was happy with Roxanne's answers, but had one more question. She noted and asked:

Roxy,
The diagram you sent (Figure 2) indicates there are volcanoes on Titan, but there is a question mark after the word Volcanism. Why is that?

Hi Gem,
The fact is, we are not sure if there is volcanism on Titan. The methane has to come from somewhere because over time, sunlight breaks it down, so it must be replenished. Processes that bring methane to the surface are a good bet and we have data indicating there are lots of circular structures that might be volcanoes, but they could also be sink holes (caused by collapse into caverns below the surface).

Hi again Roxy,
OK, how can you tell the difference between a sink hole and a volcano from space?

Hi Gemstone,
Good question! ...

a. … volcanoes can erupt explosively, which builds distinct slopes up to the vent rims. Even if the centre later collapses into a caldera structure, the elevated rim remains. Sink holes collapse into caverns so there is never an obvious elevated rim, just a hole or depression in the landscape.
b. … volcanoes can erupt lava that flows downslope across adjacent landscapes. These are often visible from space. Sink holes collapse into caverns so there is never any outwards flow of material, just a hole or depression in the landscape.
c. … volcanoes always have hot vents (that we can measure the temperature of with infrared sensors on satellites), whereas sink holes don't.
d. … She said both a & b
e. … She said both b & c.
f. … She said both a & c.