Physics 2019 v1.3

IA3 high-level annotated sample response

February 2023

Research investigation (20%)

This sample of student work has been published by the QCAA to assist and support teachers to match evidence in student responses to the characteristics described in the instrument-specific marking guide (ISMG).

The sample is an unedited authentic student response produced with permission. Any identifying features have been redacted from the response. It may contain errors and/or omissions that do not affect its overall match to the characteristics indicated.

Assessment objectives

This assessment instrument is used to determine student achievement in the following objectives:

2. apply understanding of special relativity, quantum theory or the Standard Model to develop research questions
3. analyse research evidence about special relativity, quantum theory or the Standard Model
4. interpret research evidence about special relativity, quantum theory or the Standard Model
5. investigate phenomena associated with special relativity, quantum theory or the Standard Model through research
6. evaluate research processes, claims and conclusions about special relativity, quantum theory or the Standard Model
7. communicate understandings and research findings, arguments and conclusions about special relativity, quantum theory or the Standard Model.

Note: Objective 1 is not assessed in this instrument.

Instrument-specific marking guide (ISMG)

Criterion: Research and planning

Assessment objectives

2. apply understanding of special relativity, quantum theory or the Standard Model to develop research questions
5. investigate phenomena associated with special relativity, quantum theory or the Standard Model through research

The student work has the following characteristics:	Marks
• informed application of understanding of special relativity, quantum theory or the Standard Model demonstrated by a considered rationale identifying clear development of the research question from the claim • effective and efficient investigation of phenomena associated with special relativity, quantum theory or the Standard Model demonstrated by – a specific and relevant research question – selection of sufficient and relevant sources.	5–6
• adequate application of understanding of special relativity, quantum theory or the Standard Model demonstrated by a reasonable rationale that links the research question and the claim • effective investigation of phenomena associated with special relativity, quantum theory or the Standard Model demonstrated by – a relevant research question – selection of relevant sources.	3–4
• rudimentary application of understanding of special relativity, quantum theory or the Standard Model demonstrated by a vague or irrelevant rationale for the investigation • ineffective investigation of phenomena associated with special relativity, quantum theory or the Standard Model demonstrated by – an inappropriate research question – selection of insufficient and irrelevant sources.	1–2
• does not satisfy any of the descriptors above.	0

Criterion: Analysis and interpretation

Assessment objectives

3. analyse research evidence about special relativity, quantum theory or the Standard Model
4. interpret research evidence about special relativity, quantum theory or the Standard Model

The student work has the following characteristics:	Marks
• systematic and effective analysis of qualitative data and/or quantitative data within the sources about special relativity, quantum theory or the Standard Model demonstrated by – the identification of sufficient and relevant evidence – thorough identification of relevant trends, patterns or relationships – thorough and appropriate identification of the uncertainty and limitations of evidence • insightful interpretation of research evidence about special relativity, quantum theory or the Standard Model demonstrated by justified scientific argument/s.	5–6
• effective analysis of qualitative data and/or quantitative data within the sources about special relativity, quantum theory or the Standard Model demonstrated by – the identification of relevant evidence – identification of obvious trends, patterns or relationships – basic identification of limitations of evidence • adequate interpretation of research evidence about special relativity, quantum theory or the Standard Model demonstrated by reasonable scientific argument/s.	3–4
• rudimentary analysis of qualitative data and/or quantitative data within the sources about special relativity, quantum theory or the Standard Model demonstrated – the identification of insufficient and irrelevant evidence – identification of incorrect or irrelevant trends, patterns or relationships – incorrect or insufficient identification of limitations of evidence • invalid interpretation of research evidence about special relativity, quantum theory or the Standard Model demonstrated by inappropriate or irrelevant argument/s.	1–2
• does not satisfy any of the descriptors above.	0

Criterion: Conclusion and evaluation

Assessment objectives

4. interpret research evidence about special relativity, quantum theory or the Standard Model
6. evaluate research processes, claims and conclusions about special relativity, quantum theory or the Standard Model

The student work has the following characteristics:	Marks
• insightful interpretation of research evidence about special relativity, quantum theory or the Standard Model demonstrated by justified conclusion/s linked to the research question • critical evaluation of the research processes, claims and conclusions about special relativity, quantum theory or the Standard Model demonstrated by – insightful discussion of the quality of evidence – extrapolation of credible findings of the research to the claim – suggested improvements and extensions to the investigation that are considered and relevant to the claim.	5–6
• adequate interpretation of research evidence about special relativity, quantum theory or the Standard Model demonstrated by reasonable conclusion/s relevant to the research question • basic evaluation of the research processes, claims and conclusions about special relativity, quantum theory or the Standard Model demonstrated by – reasonable description of the quality of evidence – application of relevant findings of the research to the claim – suggested improvements and extensions to the investigation that are relevant to the claim.	3–4
• invalid interpretation of research evidence about special relativity, quantum theory or the Standard Model demonstrated by inappropriate or irrelevant conclusion/s • superficial evaluation of the research processes, claims and conclusions about special relativity, quantum theory or the Standard Model demonstrated by – cursory or simplistic statements about the quality of evidence – application of insufficient or inappropriate findings of the research to the claim – ineffective or irrelevant suggestions	1–2
• does not satisfy any of the descriptors above.	0

Criterion: Communication

Assessment objectives

7. communicate understandings and research findings, arguments and conclusions about special relativity, quantum theory or the Standard Model

The student work has the following characteristics:	Marks
• effective communication of understandings and research findings, arguments and conclusions about special relativity, quantum theory or the Standard Model demonstrated by – fluent and concise use of scientific language and representations – appropriate use of genre conventions – acknowledgement of sources of information through appropriate use of referencing conventions	2
• adequate communication of understandings and research findings, arguments and conclusions about special relativity, quantum theory or the Standard Model demonstrated by – competent use of scientific language and representations – use of basic genre conventions – use of basic referencing conventions	1
• does not satisfy any of the descriptors above.	0

Context

See IA3 sample assessment instrument: Research investigation (20%) (available on the QCAA Portal).

Investigate one of the following claims:

- The theory of relativity explains the cosmos and everything in it.
- Climate change can be modelled using blackbody radiation.
- Using electrons for microscopy means there is no limit to the resolution that can be achieved.
- Quantum theories explain the origin of life.
- Bruce Banner absorbs ambient gamma radiation, converting its energy into mass during the transformation into the Hulk.

You may identify an alternative claim in consultation with your teacher. This claim must be related to Unit 4 subject matter.

Task

Gather secondary evidence related to a research question in order to evaluate the claim. Develop your research question based on a number of possible claims provided by your teacher.

Obtain evidence by researching scientifically credible sources, such as scientific journals, books by well credentialed scientists, and websites of governments, universities, independent research bodies or science and technology manufacturers. You must adhere to research conventions.

Sample response

Criterion	Marks allocated	Provisional marks
Research and planning Assessment objectives 2, 5	6	6
Analysis and interpretation Assessment objectives 2, 3, 5	6	6
Conclusion and evaluation Assessment objectives 4, 6	6	6
Communication Assessment objective 7	2	2
Total	**20**	**20**

The annotations show the match to the instrument-specific marking guide (ISMG) performance-level descriptors.

Physics IA3

Research and planning [5–6]

a considered rationale identifying clear development of the research question from the claim

The rationale communicates the sequence of ideas, supported by scientific literature, involved in the development of the research question from the claim.

Rationale

Claim: climate change can be modelled using blackbody radiation.

This claim was broken down into two main parts: climate change and blackbody radiation. In order to start initial research, a broad research question stating, 'how is climate change impacted by blackbody radiation?' was formulated.

This research found that the greenhouse effect relied heavily on blackbody radiation to be emitted into the atmosphere, and then re-absorbed by certain gases in the lowest level of atmosphere called the troposphere (Dhaniyala, 2011). Further specificity was required to understand exactly how the greenhouse effect is related to climate change.

It was found that due to an increase in the greenhouse gas concentrations in the troposphere, the amount of radiation absorbed at this level was increasing (EPA, 2019). This in-turn was leading to an increased amount of heat being 'trapped' on the surface of the Earth, leading to a process called global warming (Turrentine, 2021). After analysing multiple absorption spectra for common greenhouse gases, it was discovered that water vapor actually absorbed more radiation than CO_2, yet CO_2 is commonly considered to be the reason behind climate change (CSI, unknown). Therefore, CO_2 is included in the question. A lack of research concluded there was a relationship between water vapour and CO_2 that caused an increase in the rate of climate change. Therefore, it became the focus of the research question.

Research and planning [5–6]

a specific and relevant research question

The research question has been developed from the claim and is connected to the topics covered in the unit.

Research Question

Is there a relationship between the concentration of water-vapour and carbon dioxide greenhouse gases, that leads to an increase in the rate of global warming due to an increased absorption of blackbody radiation?

Background

A blackbody is a theoretical object that absorbs all electromagnetic radiation it is exposed to and reflects none (Swinburne University, unknown). Blackbodies also emit radiation. All things above $0^{\circ}K$ emit some form of electromagnetic radiation, acting as a blackbody (Swinburne University, unknown). When considering how the planet absorbs radiation from the sun, blackbody radiation is a key factor.

Communication [2]

fluent and concise use of scientific language and representations

Data is clearly represented so that the trends, patterns and relationships can be easily identified.

The sun emits energy in the form of electromagnetic radiation: approximately 99% of this radiation is in the form of visible light, ultraviolet and infrared (Villanueva, 2010). When this light reaches Earth, the atmosphere reflects some of this radiation and the rest is absorbed by Earth's surface (Australian Government, 2021). The surface then re-emits this light (most being infrared) into the atmosphere. Greenhouse gases (GHGs) are then responsible for absorbing some of this radiation, keeping it close to Earth's surface (Figure 1) (Australian Government, 2021). This is called the greenhouse effect and the process maintains

Communication [2]

fluent and concise use of scientific language and representations

Data is clearly represented so that the trends, patterns and relationships can be easily identified.

Earth's temperature around 33°C warmer than if there was no atmosphere (Physics Today, 2011).

Figure 1: Model of greenhouse effect. (Britannica, 2021)

Water vapour is a GHG as it also absorbs infrared radiation from Earth. A measure of the level of water vapour is humidity, or grams of vapour per kilogram of air (g/kg^{-1}) (BYJU's, unknown). When analysing the absorption spectra of this GHG (Figure 2), it can be seen that absorption occurs at 3 large points on the graph (5 in total), in comparison to CO which has 3 much smaller periods on absorption. This suggests water vapor is a more effective GHG.

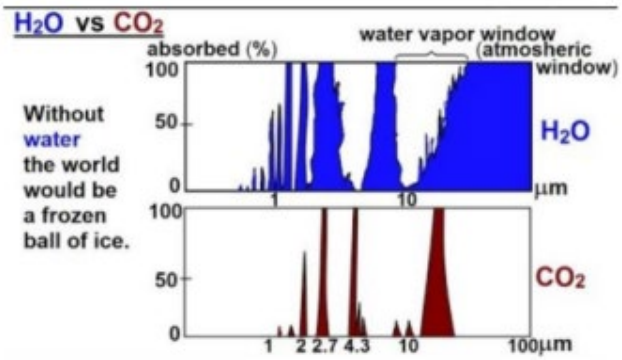

Figure 2: Absorption spectra of CO_2 and H_2O. (Google images, unknown).

Evidence

Analysis and interpretation [5–6]

identification of sufficient and relevant evidence

The evidence is appropriate for the purpose of responding to the research question. It is applicable and directly connected to the formation of the scientific argument.

M. Scheffer et. al (2006) investigated a series of historical fluctuations in carbon concentrations and climate change. At the time of publication, many believed that an increase in CO_2 emissions would increase the rate of photosynthesis, hence, leading to a negative feedback system in which the Earth could be cooled. Furthermore, the focus of the most research was understanding the effect that doubling CO_2 concentrations in the atmosphere would cause. Some estimated that this could be as high as 11.5˚C. Prior efforts to construct models proved considerably inaccurate and did not take into account positive feedback systems. Scheffer et. al believed positive feedbacks could override pre-existing negative feedbacks.

Research uncovered that as CO_2 emissions were increased, the rate of other gases, such as methane and water vapour also increased, creating

Analysis and interpretation [5–6]

thorough and appropriate identification of limitations of evidence

The response identifies limitations of evidence that affect how well it can be used to develop a response to the research question.

a positive feedback. Scheffer et. al concluded that these feedbacks could account for an increase in the rate of global warming by 15-78% on a century scale. This high level of inaccuracy does impact the validity of the model, as it is difficult to generalise. Figures 3 and 4 displayed below are predicted models displaying the effect on equilibrium with feedbacks.

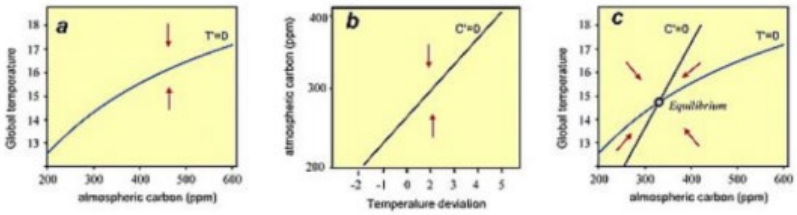

Figure 3: Graph displaying the relationship between carbon in ppm and temperature.

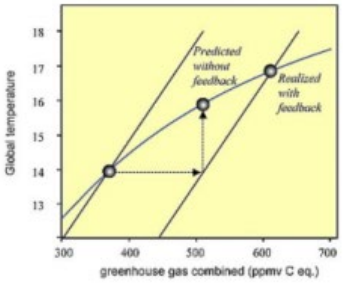

Figure 4: The proposed impact of a positive feedback on equilibrium.

Analysis and interpretation [5–6]

thorough identification of relevant trends, patterns or relationships

The identified relationships are adequate for the purpose of responding to the research question and can support a valid conclusion. They have direct bearing upon and are applicable to the formation of the scientific argument.

Figure 3 illustrates the relationship between rising temperature and greenhouse gas concentration. In context of water vapor, when the concentration increases to the point of equilibrium (intersection of lines) it will rain, leading to a decrease in water vapour. Figure 4 shows the impact the positive feedback of CO_2 concentration has on the point at which equilibrium is reached. Originally, the increase was thought to reach equilibrium at 500ppm and increase global temperature by ~2°C. The research found that the effect of the feedback would increase the ppm by a further 20% and temperature would increase a further 1°C.

Extrapolation of this data to the claim, suggests that as CO_2 is increased, water vapor feedback loops are created which introduce more GHGs to the atmosphere. This leads to increased absorption of blackbody radiation, intensifying the greenhouse effect and thus, modelling climate change.

Analysis and interpretation [5–6]

justified scientific arguments

The scientific argument communicates sound reasoning and draws upon valid and reliable evidence.

Source 2

F. Rákóczi and Z. Iványi (1999) utilised data form satellites to calculate the relationship between water vapour and the surface temperature of the Earth. They calculated the greenhouse effect (˚C) by subtracting the ground temperature from a monthly effective temperature value ($\Delta T = T_g - T_e$). The temperature difference was then graphed against the water content or humidity in the atmosphere. This is a simple calculation that does not take into account fluctuations in the weather, so the validity of this model is compromised. The findings are graphed in figure 5.

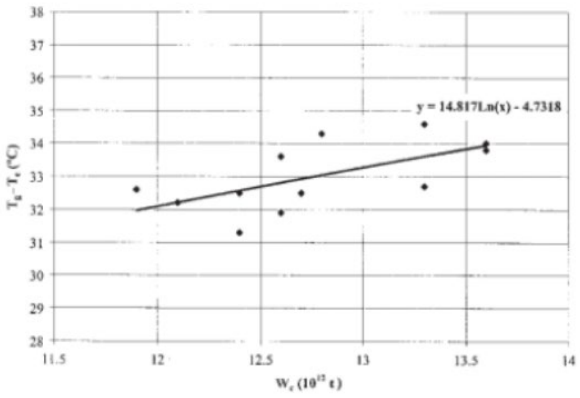

Figure 5: Relationship between humidity and temperature.

The graph above shows a clear positive linear relationship between an increasing humidity level and the greenhouse effect. The outliers for (W_e) 12.4, 12.75 and 13.5 still follow the general trend and therefore do not significantly impact the reliability of the data. The simplicity of the model are evident in such trends as it shows the relationship between water vapor and the greenhouse effect is not entirely causative. Nevertheless, this supports the claim the blackbody radiation can model climate changes, as a small increase in humidity in the atmosphere causes the greenhouse effect to intensity by 2°C due to more radiation being reflected and absorbed in the atmosphere.

Conclusion and evaluation [5–6]

extrapolation of credible findings of the research to the claim

The response identifies believable outcomes of the research and then applies them to the claim.

Source 3

G. Stephens et. al (1993) utilised data from numerous observations from varying climates around the world to understand the water vapor feedback system and its relationship to the greenhouse effect. The data was then processed using multiple formulae to create the figures seen below.

Communication [2]

acknowledgement of sources of information through appropriate use of referencing conventions

The use of in-text referencing fits the purpose of a scientific report.

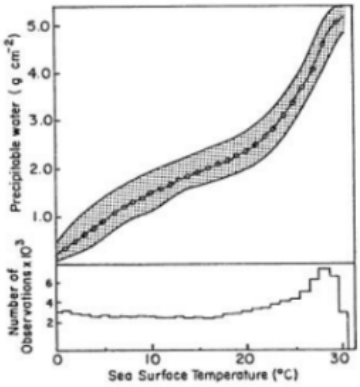

Figure 6: Relationship between surface temperature and water vapor after a 10% increase in CO_2.

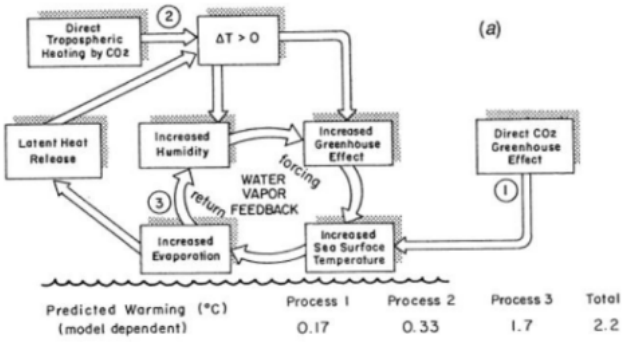

Figure 7: Theorised water vapour model process.

Figure 6 displays these results after processing data. It was found that the amount of precipitable water dramatically increased following a doubling of CO_2 which heated the environment (expressed as a surface temperature on x-axis). Specifically, as the CO_2 created more heat due to the greenhouse effect, the amount of precipitable water increased substantially. Plotted below the precipitable water-surface temperature graph, a smaller graph features the number of observations made at each temperature (in thousands). The inclusion of the graph increases the reliability and accuracy of the results.

Analysis and interpretation [5–6]

thorough identification of relevant trends, patterns or relationships

The identified patterns are adequate for the purpose of responding to the research question and can support a valid conclusion. They have direct bearing upon and are applicable to the formation of the scientific argument.

Furthermore, the pattern existing between water vapor and CO_2 is displayed in Figure 7. This model shows (from top left corner) that an increase in atmospheric CO_2 initially creates a small increase in temperature. This causes amplification of the greenhouse effect and an increased humidity. It is here the feedback loop can be observed as the surface temperature increased leading to further infrared blackbody radiation. Intriguingly, the change in temperature caused by direct increase of CO_2 concentration equates to only 22.73% of the total increase in temperature (2.2°C). Stephens et. al then concluded from this, that the water vapor feedback loop actually contributed to over half of the total increase of global warming.

Analysis and interpretation [5–6]

thorough and appropriate identification of limitations of evidence

The response identifies limitations of evidence that affect how well it can be used to develop a response to the research question.

Unfortunately, due to the equilibrium on Earth that leads to precipitation, the long-term extent of this feedback loop was hard to determine. This model is also very general and different climates would experience varied impacts. Furthermore, the article was written when there was less of an understanding of the equilibrium, meaning the results found were broad and may have only been accurate for a proportion of models both modern and past.

Interpretation

Analysis and interpretation [5–6]

justified scientific arguments

The scientific argument communicates sound reasoning and draws upon valid and reliable evidence.

Extrapolation of the data suggests that when atmospheric CO_2 concentration is increased, a process called 'water-vapor feedback' takes place which enhances the GHG concentration. This leads to higher amounts of blackbody radiation being absorbed, facilitating climate change. Hence, the research supports the claim.

Evaluation

Scheffer et. al (2006), F. Rákóczi and Z. Iványi (1999), and Stephens et. al (1993) all provide evidence in their articles that is complementary. The

Conclusion and evaluation [5–6]

insightful discussion of the quality of evidence

The discussion communicates understanding of the features of the evidence that affect how well it can be used to respond to the research question.

researcher's all predicted that this process is accountable for more than half of the intensifying greenhouse effect that is leading to global warming, through varying methods of data, hence, the sources are reliable.

However, all sources are largely impacted by validity. Scheffer et. al and Stephens et. al both made direct reference to the inaccuracies associated with the models and data. Specifically, the variation in tropical and arid climates created large uncertainty in the data and make it less representative of the global climate. Furthermore, due to the number of different feedback systems happening globally such as photosynthesis, finding the effect that this feedback has (by isolating it form the rest) is difficult and inaccurate. Scheffer et. al predicted the impact of the water vapor effect to equate for 15-78% of the total global warming. Similarly, Stephens et. al concluded that water vapor accounted for 'more than half' of the total greenhouse effect but failed to make an exact value due to the acknowledged inaccuracy.

Another limitation of the research is the age of the data which impacts its reliability. Although global warming is an increasingly researched topic, data around water vapor feedback is less focussed on how much it influences climate change, and more focussed on finding methods to reduce CO_2 concentrations to stop this feedback from occurring.

Conclusion

Conclusion and evaluation [5–6]

justified conclusion/s linked to the research question

The response uses sound reasoning drawing upon valid and reliable evidence to support conclusions that directly respond to the research question.

To encapsulate the evidence provided in this report the research question, 'is there a relationship between the concentration of water-vapor and carbon dioxide greenhouse gases that leads to an increase in the rate of global warming?' can be answered confidently. It was found that the relationship linking these greenhouse gases is called the water vapor feedback. It is facilitated by an increase in atmospheric CO_2 which consequently increases the humidity, hence, magnifying the greenhouse effect. The claim, 'climate change can be modelled using blackbody radiation' can be partially supported as all sources' relied heavily on metaphorical situations and were largely affected by error due to the complicated process which changes depending on the climate. In order to increase the reliability and validity to fully support the claim the following improvements and extensions should be considered in the future.

Improvements and Extensions

Conclusion and evaluation [5–6]

suggested improvements and extensions to the investigation, which are considered and relevant to the claim

The response uses the analysis of the investigations limitations to inform suggested improvements that are connected to the claim.

To address the limitations of the evidence, the following improvements and extensions should be considered in the future:

- Improvement: finding data that is specific for different climates around the world in order to communicate accurate models that represent the globe, hence, improving validity.
- Improvement: Finding more recent models that includes satellite data to visualise how the presence of water vapour from the feedback loop actually increases temperature. This would improve the reliability and validity of the findings as they would have a more realistic context rather than hypothetical.

Conclusion and evaluation [5–6]

suggested improvements and extensions to the investigation, which are considered and relevant to the claim

The extensions identify modifications that would complement the findings of the investigation and have the potential to provide new evidence that could be used to evaluate the claim further.

- Extension: research further if other common greenhouse gases such as sulphur dioxide, nitrous oxide and methane have similar feedback systems present that add to the greenhouse effect.
- Extension: investigate the modern understanding of how humidity, atmospheric pressure and carbon impact the temperature at which precipitation (equilibrium) is reached and how it is changed due to the feedback systems (mentioned in Source 1: Scheffer et. al (2006).

Word count:1985

Bibliography

American Chemist Society. (unknown). *What are the properties of a greenhouse gas?* Retrieved from ACS: https://www.acs.org/content/acs/en/climatescience/greenhousegases/properties.html

Australian Government. (2021). *Greenhouse effect.* Retrieved from Autralian Government: Department of Agriculture, water and Environment: https://www.environment.gov.au/climate-change/climate-science-data/climate-science/greenhouse-effect

Brittannica. (2021). *Greenhouse effect.* Retrieved from Atmospheric science: https://www.britannica.com/science/greenhouse-effect

BYJU's. (unknown). *Unit of Humidity.* Retrieved from BYJU's Classes: https://byjus.com/physics/unit-of-humidity/

CSI. (unknown). *The Greenhouse Effect.* Retrieved from Energy: Driver of Climate Change: http://www.ces.fau.edu/nasa/module-2/how-greenhouse-effect-works.php

Dahlman, R. L. (March). *Climate Change: Global Temperature.* Retrieved from Climate.gov: https://www.climate.gov/news-reatures/understanding-climate-change-global-temperature

Dhaniyala, S. (2011, August)). *Greenhouse Effect.* Retrieved from Clarkson University: https://www.clarkson.edu/stem/project-based-climate-modules/greenhouse-effect

EPA. (2019). *Sources of Greenhouse Gas Emissions*. Retrieved from Environmental Protection Agency: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Google images. (unknown). *Absorption spectra of CO_2 and water vapour.*

Iványi, F.R. (1999, June). *Water Vapor Feedback and Greenhouse Effect.* Retrieved from Geofizika: file:///C:/Users/61457/Downloads/16127-Article%20Text-56878-1-10-20210329%20(3).pdf

Marten Scheffer, V. B. (2006, May). *Positive feedback between global warming and atmospheric CO_2 concentration inferred from past climate change*. Retrieved from AGU: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2005GL025044

Research and planning [5–6]

selection of sufficient and relevant resources

Sources throughout the response are scientific and provide enough evidence for the development of a scientific argument that responds to the research question.

Communication [2] **acknowledgement of sources of information through appropriate use of referencing conventions** Sources of information are acknowledged using a referencing style that is suitable for the purpose of the essay.	Physics Today. (2011, January). *Infrared radiation and planetary temperature.* Retrieved from Physics Today: https://physicstoday-scitation-org.ezproxy.library.uq.edu.au/doi/full/10.1063/1.3541943 Reisinger, M. M. (2011, May). Broader perspectives for comparing different greenhouse gases. Retrieved from The Royal Society Publisher: https://royalsocietypublishing.org/doi/full/10.1098/rsta.2010.0349 Soden, I. H. (2000). *Water Vapor Feedback and Global Warming.* Retrieved from Annual Reviews: https://www.annualreviews.org/doi/pdf/10.1146/annurev.energy.25.1.441 Swinburne University. (unknown). *Blackbody Radiation*. Retrieved from Cosmos: https://astronomy.swin.edu.au/cosmos/b/blackbody+radiation Tjemkes, G. S. (1993). *Water Vapor and Its Role in the Earth's Greenhouse*. Retrieved from Harvard.edu: http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?bibcode=1993AuJPh..46..149S&db_key=AST&page_ind=0&data_type=GIF&type+SCREEN_VIEW&classics=YES Turrentine, A.M. (2021, April). *Global Warming 101*. Retrieved from Natural Resources Defense Council, Inc.: https://www.nrdc.org/stories/global-warming-101 Villanueva, J. (2010). *Radiation from the sun*. Retrieved from Universe Today: https://www.universetoday.com/60065/radiation-from-the -sun/