Asian Physics Olympiad 2019 Proceedings

Contents

Preface

It was a great honour for Australia to host the 20th Asian Physics Olympiad in Adelaide, South Australia.

This prestigious event provided a unique platform to showcase Australia's rich cultural heritage and world-class education and scientific research facilities.

It also provided opportunities for Asia's best physics students to be academically challenged and rewarded, and establish new friendships that we hope one day will lead to future international collaborations. In a time when science is truly an international pursuit, it is opportunities like the Asian Physics Olympiad that can be life-changing.

We thank the Australian Government for their support of this event through the National Innovations and Science Agenda, our University partners and Westpac and Toshiba for their contribution to the success of the 20th Asian Physics Olympiad.

We wish all our new friends that took part in the 20th Asian Physics Olympiad much success in the future.

Trevor Danos AM
Chair, APhO 2019 Organising Committee

Preface

The Olympiad movement is about connecting young people from different cultures with a shared love and passion for learning in a specific field. Australia has participated in the APhO since its inception in 2000, and so organising the 2019 Asian Physics Olympiad in Adelaide, Australia was our opportunity to provide students from our region an experience with both genuinely challenging physics problems, and the chance to form networks while having fun amongst some of the beautiful Australian scenery.

Australian Science Innovations, with the support of the Australian Government, our University partners and other key sponsors, led the significant task of organising the APhO. An amazing number of people contributed their time and energy to make the event a success and, as Chair of the Academic Committee, I thank each and every one of them for their dedication. Preparing the problems both theoretical and experimental, the Academic Committee aimed to provide a genuine test of experimental skills and scope to play, and a range of theoretical problems allowing all students to access the questions but providing plenty of challenge at the high end.

These proceedings contain a record of the problems, solutions and activities throughout the 20th APhO and pay tribute to the people involved. Most of all, they are not just a record of the event but a symbol of the health and vitality of the Asian Physics Olympiad community in its 20th year.

Dr Matthew Verdon
Chair, APhO 2019 Academic Committee

Organisation

Academic Committee

The APhO 2019 Academic Committee members are:

- Dr Matthew Verdon (Chair) – Australian Science Innovations
- Dr Alix Verdon – Australian Science Innovations
- Associate Professor Andrew McKinnon – University of Adelaide
- Professor Jamie Quinton – Flinders University
- Associate Professor Shahraam Afshar – University of South Australia
- Professor David Lancaster – University of South Australia

Organising Committee

The APhO 2019 Organising Committee members are:

- Trevor Danos AM (Chair)
- Tracey Byrne – Australian Science Innovations
- Ruth Carr – Australian Science Innovations
- Debra Smith – Australian Science Innovations
- Dr Matthew Verdon – Australian Science Innovations

Staff- Australian Science Innovations

- Tracey Byrne
- Ruth Carr
- Vanessa Kates
- Yelena Ramli
- Geraldine Stringer
- Dr Alix Verdon
- Dr Matthew Verdon

Volunteers

- Janith Adikaram Mudiyanselage
- Shahraam Afshar
- Lee Atkinson
- Harrison Barnett
- Dewiilarlina Batubara
- Eva Bezak
- Anha Bhat
- James Biddle
- Chris Boyd
- Jane Bray
- Mary Bryker
- Gunilla Burrowes
- Grace Byrne
- Sai Campbell
- Ryan Campbell
- Wenjun (Eve) Cheng
- Milad Dakka
- Aidan Dang
- Trevor Danos
- Sri Yunita Dareng
- Jesse Daughtry
- Anna Davis
- Alistair de Vroet
- Boris Deletic
- Graham Dennis
- Rajina Dhillon
- Thomas Dixon
- Shankar Dutt
- Stuart Earl
- Yola Eka Erwinda
- Melanie Field
- Tracey Fulwood
- Marc Gali
- Christoph Gerber
- Gabriela Grace
- Minh Tan Ha
- Kerrilie Haberfield
- Mengke Han
- Violet Harvey
- Johnathan Hedger
- Fabio Henriques
- Oliver Hervir
- Tahni Hinchley
- Maryam Hor
- Michael Horn
- Jaslyn Hughes
- Tim Hume
- Wasif Husain
- Sam Huynh
- Cahit Kargi
- Faisal Karim
- Slava Kascheyevs
- Georgio Katsifis
- Yaroslav Kharkov
- David Lancaster
- Daniel Lawson
- Yongqin Li
- Charlotte Li
- Maksim Lisau
- Cut Mayang
- Cathryn McDonald
- Sarah McDonnell
- Lachlan McGinness
- Andrew McKinnon
- Geoffrey McNulty
- Vladimir Mikho
- Jack Moran
- Sebastian Murk
- Phuong-Cac Nguyen
- Daniel Oldfield
- Dale Otten
- Zoe Pettifer
- Lucy Pfiefer
- Dian Dini Primadani
- Jamie Quinton
- Carol Rance
- Connor Retallick
- Yuliani Romea
- Jed Rowland
- Diane Salim
- Aidan Sawers
- Grant Schuster
- Mackenzie Shaw
- Vittala Shettigara
- David Shin
- Dylan Siow-Lee
- Sabrina Slimani
- Susan Soleil
- Campbell Strachan
- Hao Sun
- Dagmawi Tadesse
- Sara Tanovic
- Nishka Tapaswi
- Jade Taylor
- Krishne Thayaparan
- Hoang Bao Tran Tan
- Naga Tumuluri
- Nikka Turangan
- Adam Virgili
- Wiktoria Wojtaczka
- Claire Wright
- Claire Yung
- Ming Yung
- Stephen Zander
- Peter Zander
- Bonnie Zhang
- Wenqi Zhang
- Janet Zhong
- Yi Yi Zhong

Supporters

The opportunities provided by the Asian Physics Olympiad could not be possible without the generosity from our supporters.

Major Supporter

Australian Government
Department of Industry, Innovation and Science

Australian Government
Department of Defence
Science and Technology

Government of South Australia

Australian Government
ANSTO

THE UNIVERSITY of ADELAIDE

Flinders UNIVERSITY
College of Science & Engineering

University of South Australia

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Participating Countries & Regions

22 countries and regions participated in the Asian Physics Olympiad 2019.

Australia	Mongolia
Bangladesh	Romania
Cambodia	Russia
China	Saudi Arabia
Hong Kong	Singapore
India	Sri Lanka
Indonesia	Taiwan
Israel	Thailand
Kazakhstan	Turkey
Macau	United Arab Emirates
Malaysia	Vietnam

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Participants

Australia		
Keeley	Hoek	Team Leader
Siobhan	Tobin	Team Leader
Stephen	Catsamas	Student
Benjamin	Davison-Petch	Student
Min-Je	Hwang	Student
Alexander	Lin	Student
Jessie	Lum	Student
William	Sutherland	Student
Simon	Yung	Student
Rosemary	Zielinski	Student
Zoe	Schwerkolt	Observer
Bangladesh		
Fayez Ahmed	Jahangir Masud	Team Leader
M Arshad	Momen	Team Leader
Md Fahim	Abrar	Student
Km Meshkat Bin	Alam	Student
Golam	Ishtiak	Student
Rubayat	Jalal	Student
Tasnimul	Jishan	Student
Imtiaz Tanweer	Rahim	Student
Sheikh	Shafayat	Student
Ashirin	Tashin	Student
Cambodia		
Kimleang	Khun	Team Leader
Kalyan	Sou	Team Leader
Huy Kheang	Eang	Student
Kim Seng	Lay	Student
Khem Raksa	Peou	Student
Puth Srey Neath	Pich	Student
Leanghak	Seng	Student
Thach	Kim	Observer
Ngo Hok	Ung	Observer

China		
Yu	An	Team Leader
Shuo	Jiang	Team Leader
Kangyao	Chen	Student
Shu	Chen	Student
Wentai	Deng	Student
Junjie	Li	Student
Xiaoyi	Shi	Student
Yuqin	Wang	Student
Ruoyu	Yan	Student
Zhelun	Zhang	Student
Xubo	Guo	Observer
Cheng	Qian	Observer
Dong	Ruan	Observer
Liuwan	Zhang	Observer
Hong Kong		
Ting-Pong	Choy	Team Leader
Kwok-Yee, Michael	Wong	Team Leader
Leong-Chit, Jeff	Kwan	Student
Sze-Chun	Lau	Student
Wan	Lee	Student
Tat-Sang	Li	Student
Jianchen	Lu	Student
Chi-Kin	Ng	Student
Chun	Szeto	Student
Shi	Cheung	Observer
India		
Mukund Laxman	Ogalapurkar	Team Leader
Pramendra Ranjan	Singh	Team Leader
Harshvardhan	Agarwal	Student
Dhruv	Arora	Student
Tejas	Bansod	Student
Dhruv Kumar	Gupta	Student
Lakshya Yogesh	Gupta	Student
Niyati Manishkumar	Mehta	Student
Ravi Shankar	Bhattacharjee	Observer

Indonesia		
Zainul	Abidin	Team Leader
Herry Johnny	Kwee	Team Leader
Daffa Fathani	Adila	Student
Gusti Putu Surya Govinda	Atmaja	Student
Muhammad Morteza	Mudrick	Student
Hudzaifah Afif Al Fatih	Nasution	Student
Yuwanza	Ramadhan	Student
Ivander Jonathan Marella	Waskito	Student
Nixon	Widjaja	Student
Hendra Johnny	Kwee	Observer
Israel		
Nitzan Shalom	Artzy	Team Leader
Ben Akiva	Feinstein	Team Leader
Yonatan	Hassoun	Student
Teddy	Klaytman	Student
Ziv Or	Kohn	Student
Eran	Mann	Student
Omri	Reved	Student
Liad	Rovnick Teutsch	Student
Aviv	Tillinger	Student
Eyal	Walach	Student
Dagan	Ashash	Observer
Gur	Perri	Observer
Kazakhstan		
Pavel	Levchenko	Team Leader
Samat	Maxutov	Team Leader
Amirkhan	Bailin	Student
Yaroslav	Bassov	Student
Temirlan	Ismagulov	Student
Dias	Les	Student
David	Li	Student
Rassul	Magauin	Student
Diyar	Tulenov	Student
Alexey	Yanchenko	Student

Macau		
Iat Neng	Chan	Team Leader
Kwun Nam	Hui	Team Leader
Weng Ian	Chan	Student
Zhukun	Chen	Student
Zhuzhen	Fan	Student
Hiu Nam	Leong	Student
Man Fong	Lio	Student
Chon Hei	Lo	Student
Pak Lam	Lo	Student
Franlklin Hor Chung	Yeung	Student
Malaysia		
Poh	Seong Foi	Team Leader
Goh	Teck Ang	Team Leader
Siow	Cheng Bo	Student
Loh	Guo Jun	Student
Tan	Jia Qing	Student
Ting	Jin Khang	Student
Lim	Poh Seng	Student
Yap	Shaw Bin	Student
Takeda	Shigenori	Student
Chan	Tin Ping	Student
Tan	Chee Siang	Observer
Mongolia		
Munkhbayar	Gombosuren	Team Leader
Otgonbaatar	Myagmar	Team Leader
Tsolmon	Bazarragchaa	Student
Khongor	Damdinbayar	Student
Itgel	Delgerdalai	Student
Temuujin	Delgertsogt	Student
Enkhjin	Gankhuyag	Student
Bat-Orgil	Orgilsaikhan	Student
Bat-Orgil	Sainbuyan	Student
Saikhanbileg	Sugar	Student
Bulgamaa	Battsogt	Observer

Romania		
Adrian	Dafinei	Team Leader
Delia - Constanta	Davidescu	Team Leader
Ionel - Emilian	Chiosa	Student
Stefan	Dolteanu	Student
Sabina	Dragoi	Student
Marius	Ignat	Student
Theodor	Iosif	Student
Vlad	Rosca	Student
Mihai	Vasile	Student
Ariana - Dalia	Vlad	Student
Russia		
Vitaly	Shevchenko	Team Leader
Fedor	Tsybrov	Team Leader
Grigorii	Bobkov	Student
Irina	Lialikova	Student
Vladimir	Malinovskii	Student
Andrei	Panferov	Student
Vladislav	Poliakov	Student
Aleksei	Shishkin	Student
Pavel	Shishkin	Student
Elisei	Sudakov	Student
Alexey	Alekseev	Observer
Iurii	Skakov	Observer
Saudi Arabia		
Essa	Alfaifi	Team Leader
Jaan	Kalda	Team Leader
Rawan	Alghamdi	Student
Ahmad	Alhaid	Student
Yazan	Almajnouni	Student
Hisham	Almalki	Student
Ahmed	Almuhanna	Student
Moaaz	Fayumy	Student
Husam	Noorwli	Student
Alqasem	Senegali	Student
Saleha	Ali	Observer
Mohammed	Almalki	Observer

Singapore		
Paul	Lee	Team Leader
Qinghai	Wang	Team Leader
Sidharth	Chambocheri Veetil	Student
Jiakai	Chen	Student
Shu	Ge	Student
Jeffrey	Lee	Student
Bryant	Li	Student
Raviraj Ramchandra	Talgeri	Student
Vishnuprasath	Vijayaraghavan	Student
Xiaorui	Zhang	Student
Zhiyin	Kee	Observer
Fabiola	Lip	Observer
Da Yang	Tan	Observer
Sri Lanka		
Hewa Hakuru	Sumathipala	Team Leader
Jayakody Ralalage	Pemadasa Jayakody	Team Leader
Wijepala Abeysinghe Mudiyanselage Samitha Yohan	Abeysinghe	Student
Thishanka	Alahakoon	Student
Sahan Manodya	Karawita	Student
Kodithuwakkara Gedara Pramod Chathuranga	Karunasena	Student
Chamath	Sandaru	Student
Kavindu	Weerasinghe	Student
Hettikankanange Thevindu Janith	Wijesekera	Student

Taiwan		
Hsien-Chung	Kao	Team Leader
Shang-Fang	Tsai	Team Leader
Yu-Chi	Chang	Student
Chin-Yi	Lin	Student
Chih-Chen	Liu	Student
Pei-Rui	Luo	Student
Yeu-Guang	Tung	Student
Wei-En	Wang	Student
Cheng-Hao	Yang	Student
Ching-Yu	Yao	Student
Yu-Chiang	Chao	Observer
Hong-Yi	Chen	Observer
Chih-Ta	Chia	Observer
Hsiang-Chih	Chiu	Observer
Tsu-Yi	Fu	Observer
Ming-Jie	Li	Observer
Chung-Yu	Mou	Observer
Sheng-Yun	Wu	Observer
Thailand		
Wittaya	Kanchanapusakit	Team Leader
Monsit	Tanasittikosol	Team Leader
Thitipat	Jandrapirat	Student
Junlajak	Jongpipattanakul	Student
Pakorn	Nunta-Aree	Student
Yanaphat	Pinijpichitkul	Student
Passakorn	Potanunt	Student
Laphas	Premcharoen	Student
Nop	Toemtrisna	Student
Sorawit	Udomphonchaicharoen	Student
Tawinan	Cheiwchanchamnangij	Observer
Nirut	Pussadee	Observer
Kitchaphol	Tiewpudza	Observer

Turkey		
Salih	Aksoy	Team Leader
Haci Ahmet	Yildirim	Team Leader
Kutay	Akin	Student
Berkin	Binbas	Student
Oyku Sila	Guner	Student
Alkin	Kaz	Student
Yunus Emre	Parmaksiz	Student
Bayram Alp	Sahin	Student
Alper	Tezcan	Student
Mert	Unsal	Student
United Arab Emirates		
Subramanian	Krishnamoorthy	Team Leader
Sachin	Saini	Team Leader
Jagrit	Digani	Student
Isaiah	Kuruvilla	Student
Nisarg Pratikkumar	Shah	Student
Kavya	Shri	Student
Vietnam		
Huy Hoang	Luc	Team Leader
The Khoi	Nguyen	Team Leader
Cong Minh Hieu	Le	Student
Quang Huy	Le	Student
Viet Hoang	Le	Student
Khanh Linh	Nguyen	Student
Xuan Tan	Nguyen	Student
Xuan Ung	Nguyen	Student
Xuan Tung	Tran	Student
Duy Hieu	Trinh	Student
Quoc Anh	Le	Observer
Thi Thu Dinh	Ngo	Observer
Cong Toan	Nguyen	Observer
Van Thu	Nguyen	Observer
Cong Hong	Sai	Observer
Le Quang	Trieu	Observer

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Student Results

Gold		
First Name	Last Name	Delegation
Grigorii	Bobkov	RUSSIA
Ruoyu	Yan	KAZAKHSTAN
Zhelun	Zhang	CHINA
Aviv	Tillinger	ISRAEL
Kangyao	Chen	CHINA
Xiaoyi	Shi	CHINA
Wentai	Deng	CHINA
Shu	Chen	CHINA
Aleksei	Shishkin	RUSSIA
Silver		
First Name	Last Name	Delegation
Vladimir	Malinovskii	RUSSIA
Junjie	Li	CHINA
Vladislav	Poliakov	RUSSIA
Sidharth	Chambocheri Veetil	SINGAPORE
Wei-En	Wang	TAIWAN
Ching-Yu	Yao	TAIWAN
Dhruv	Arora	INDIA
Nixon	Widjaja	INDONESIA
Leong-Chit, Jeff	Kwan	HONG KONG
Eyal	Walach	ISRAEL
Andrei	Panferov	RUSSIA
Duy Hieu	Trinh	VIETNAM
Shu	Ge	SINGAPORE
Elisei	Sudakov	RUSSIA
Cheng-Hao	Yang	TAIWAN
Xuan Ung	Nguyen	VIETNAM

2019 Asian Physics Olympiad Gold (left) and silver (right) Medallists

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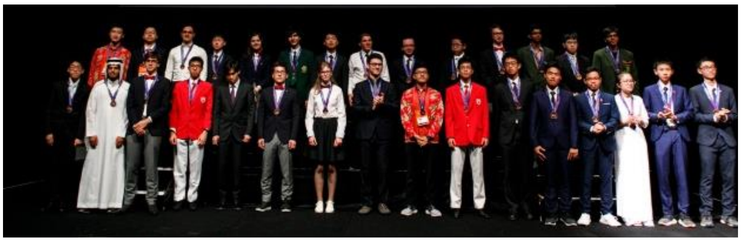
Bronze		
First Name	Last Name	Delegation
Yuqin	Wang	CHINA
Yunus Emre	Parmaksiz	TURKEY
Yeu-Guang	Tung	TAIWAN
Ariana-Dalia	Vlad	ROMANIA
Stephen	Catsamas	AUSTRALIA
Chin-Yi	Lin	TAIWAN
Eran	Mann	ISRAEL
Berkin	Binbas	TURKEY
Sze-Chun	Lau	HONG KONG
Mihai	Vasile	ROMANIA
Chun-Wang	Chau	HONG KONG
Dhruv Kumar	Gupta	INDIA
Lakshya Yogesh	Gupta	INDIA
Ivander Jonathan Marella	Waskito	INDONESIA
Xiaorui	Zhang	SINGAPORE
Pei-Rui	Luo	TAIWAN
Diyar	Tulenov	KAZAKHSTAN
Ionel-Emilian	Chiosa	ROMANIA
Rassul	Magauin	KAZAKHSTAN
Irina	Lialikova	RUSSIA
Alkin	Kaz	TURKEY
Hudzaifah Afif Al Fatih	Nasution	INDONESIA
Jiakai	Chen	SINGAPORE
Yu-Chi	Chang	TAIWAN
Xuan Tan	Nguyen	VIETNAM
Viet Hoang	Le	VIETNAM
Khanh Linh	Nguyen	VIETNAM
Cong Minh Hieu	Le	VIETNAM
Xuan Tung	Tran	VIETNAM
Yazan	Almajnouni	SAUDI ARABIA
Amirkhan	Bailin	KAZAKHSTAN
Theodor	Iosif	ROMANIA
Tat-Sang	Li	HONG KONG

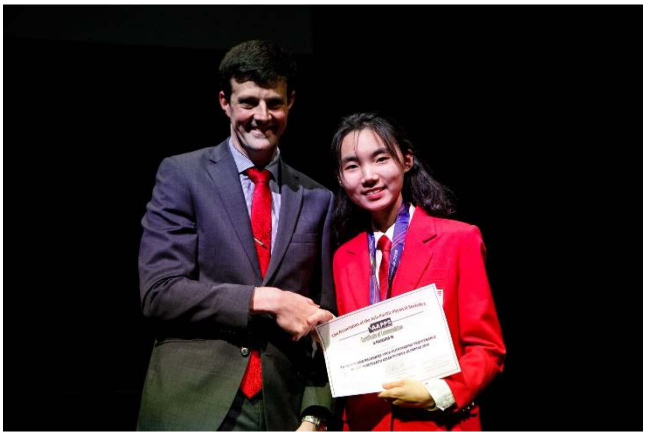


2019 Asian Physics Olympiad Bronze Medallists

Honourable Mention		
Omri	Reved	ISRAEL
Stefan	Dolteanu	ROMANIA
Yanaphat	Pinijpichitkul	THAILAND
Bryant	Li De Hou	SINGAPORE
Vlad	Rosca	ROMANIA
Chih-Chen	Liu	TAIWAN
Jianchen	Lu	HONG KONG
Passakorn	Potanunt	THAILAND
Mert	Unsal	TURKEY
Niyati Manishkumar	Mehta	INDIA
Vishnuprasath	Vijayaraghavan	SINGAPORE
Pavel	Shishkin	RUSSIA
Wan	Lee	HONG KONG
Thitipat	Jandrapirat	THAILAND
Kutay	Akin	TURKEY
Tan	Jia Qing	MALAYSIA
Daffa Fathani	Adila	INDONESIA
Quang Huy	Le	VIETNAM
Rosemary	Zielinski	AUSTRALIA
Gusti Putu Surya Govinda	Atmaja	INDONESIA
Pakorn	Nunta-Aree	THAILAND
Harshvardhan	Agarwal	INDIA
Tsolmon	Bazarragchaa	MONGOLIA
Laphas	Premcharoen	THAILAND
Yuwanza	Ramadhan	INDONESIA
Muhammad Morteza	Mudrick	INDONESIA
Marius	Ignat	ROMANIA
Simon	Yung	AUSTRALIA
Sorawit	Udomphonchaicharoen	THAILAND

2019 Asian Physics Olympiad Honourable Mention recipients

Special Prizes		
Overall Winner of the Asian Physics Olympiad	Grigorii Bobkov	RUSSIA
Theoretical Winner	Ruoyu Yan	CHINA
Theoretical Runner-up	Kangyao Chen	CHINA
Experimental Winner	Rassul Magauin	KAZAKHSTAN
Experimental Runner-up	Vladimir Malinovskii	RUSSIA
Best Female Performer	Shu Ge	SINGAPORE
Best Australian Performer	Stephen Catsamas	AUSTRALIA
President's Awards		
Best Male Performer	Grigorii Bobkov	RUSSIA
Best Female Performer	Shu Ge	SINGAPORE
Most Creative Solution in Theoretical Exam	Grigorii Bobkov	RUSSIA
Most Creative Solution in Experimental Exam	Chun-Wang Chau	HONG KONG
Most Deserving Male Student	Simon Yung	AUSTRALIA
Most Deserving Female Student	Rosemary Zielinski	AUSTRALIA



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Program Overview

Student Program

Date	Time	Activity
Sun 5 May		Arrivals- All day
	18.30 - 19.30	Dinner at hotel
Mon 6 May	06.30 – 09.00	Breakfast
	10.00 – 11.00	Opening Ceremony at Adelaide Convention Centre
	11.00 – 12.00	Lunch at Adelaide Convention Centre
	12.30 – 14.30	School Experience
	18.30 – 19.30	Dinner at hotel
Tue 7 May	06.00 – 07.00	Breakfast
	08.00 – 13.00	Exam 1 at Adelaide Convention Centre
	13.00 – 14.00	Lunch at Adelaide Convention Centre
	15.00 – 17.00	Cultural Experience
	18.30 – 19.30	Dinner at hotel
Wed 8 May	06.30 – 09.00	Breakfast
	10.00 – 12.30	Cleland Wildlife Park
	12.30 – 13.00	Lunch at Cleland Wildlife Park
	14.30 – 16.00	Australian University Experience
	18.30 – 19.30	Dinner at hotel
Thu 9 May	06.00 – 07.00	Breakfast
	08.00 – 13.00	Exam 2 at Adelaide Convention Centre
	13.00 – 14.00	Lunch at Adelaide Convention Centre
	14.45 – 17.30	Sporting Experience
	18.30 – 20.30	Reunion Dinner at the Hilton Hotel
	20.30 –22.00	Student Cultural Exchange

Date	Time	Activity
Fri 10 May	06.30 – 09.00 10.00 – 11.20 12.00 – 13.00 13.30 – 17.00 17.00 – 23.15 18.30 – 19.30	Breakfast APhO Address Lunch at the University of Adelaide Cultural Experience (Group A) Stockport Observatory (Group B) Dinner at hotel
Sat 11 May	06.30 – 09.00 10.00 – 12.00 12.30 – 13.30 13.30 – 16.00 17.00 – 23.15 18.30 – 17.30	Breakfast Glenelg Surf Lifesaving Club Lunch at Glenelg Surf Life Saving Free time at Glenelg Precinct (Group B) Stockport Observatory (Group A) Dinner at hotel
Sun 12 May	06.30 – 11.00 09.00 – 12.00 11.00 – 12.00 12.30 – 13.30 15.30 – 17.30 18.00 – 22.00	Breakfast Free time (Group A) Lunch at hotel (Group B) Lunch at hotel Closing Ceremony at Adelaide Convention Centre Dinner and Celebration at Adelaide Convention Centre
Mon 13 May	06.30 – 10.30	Breakfast

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Team leaders & Observers

Date	Time	Activity
Sun 5 May		Arrivals – All Day
	18.30 - 20.00	Dinner at hotel
Mon 6 May	06.00 – 09.00	Breakfast
	10.00 – 11.00	Opening Ceremony at Adelaide Convention Centre
	11.00 – 12.00	Lunch at Adelaide Convention Centre
	12.30 – 18.30	Paper discussion and translation
	18.30 – 19.30	Dinner at hotel
	19.30 – 22.30	Paper discussion and translation
Tue 7 May	06.00 – 09.30	Breakfast
	10.00 – 12.00	Adelaide Central Market Tour
	12.00 – 13.00	Lunch at Adelaide Central Market
	13.00 – 18.30	Free Time
	18.30 – 20.00	Dinner at hotel
		Distribution of Exam 1
Wed 8 May	06.00 – 09.00	Breakfast
	09.00 – 12.30	Paper discussion and translation
	12.30 – 13.30	Lunch at hotel
	13.30 – 18.30	Paper discussion and translation
	18.30 – 19.30	Dinner at hotel
	19.30 – 22.30	Paper discussion and translation
Thu 9 May	06.00 – 09.30	Breakfast
	10.00 – 12.00	Cultural Experience at South Australian Museum
	12.00 – 13.00	Lunch at the South Australian Museum
	13.30 – 16.00	Adelaide Oval tour
	18.30 – 20.30	Reunion Dinner at the Hilton Hotel
		Distribution of Exam 2

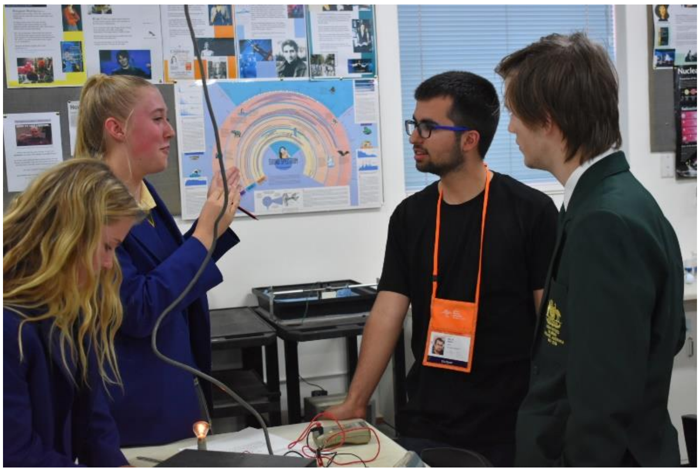
Date	Time	Activity
Fri 10 May	06.00 – 09.30 11.00 – 14.30 15.30 – 18.00 18.30 – 19.30	Breakfast Cleland Wildlife Park, including lunch Free time at Glenelg Precinct Dinner at Glenelg Surf Life Saving Club
Sat 11 May	06.00 – 10.30 09.00 – 12.00 12.30 – 13.30 13.30 – 18.00 18.30 – 20.00 20.00 – 21.30	Breakfast Free time Lunch at hotel Moderation at Adelaide Convention Centre Dinner at hotel International board meeting
Sun 12 May	06.00 – 10.30 09.00 – 12.00 12.30 – 13.30 15.30 – 17.30 18.00 – 22.00	Breakfast Free time Lunch at hotel Closing Ceremony at Adelaide Convention Centre Dinner and Celebration at Adelaide Convention Centre
Mon 13 May	06.00 – 10.30	Breakfast

School Visits

Monday 6 May 2019

Following the Opening ceremony, students were split into 10 groups. Each group visited the following local schools for a cultural exchange:

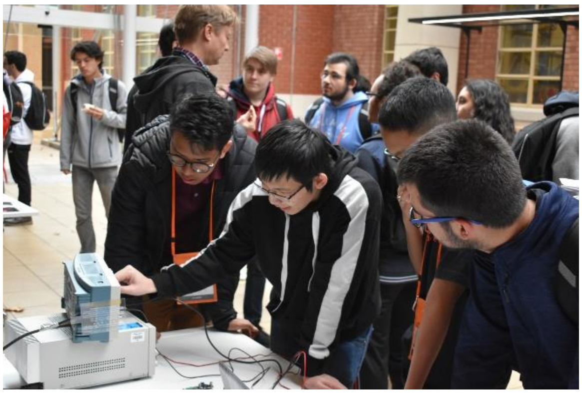
- Adelaide High School
- Woodville High School
- Unley High School
- Heathfield High School
- Pembroke School
- Prince Alfred College
- St Peter's College
- Mitcham Girls High School
- University Senior College
- Golden Grove High School



APhO Address

Friday 10 May

Students attended a lecture from leading researcher in quantum computing and 2018 Australia of the Year, Professor Michelle Simmons held at the University of Adelaide.



Cleland Wildlife Park

Wednesday 08 May

Students visited Cleland Wildlife Park for their excursion day. At the park they were able to get up close to some of Australia's iconic animals including kangaroos and koalas.

Opening Ceremony

Date: Monday 06 May 2019

Time: 1000 - 1100

Location: Adelaide Convention Centre

Time	Function	Talent
0950 - 1000	Guest arrival and seated	
1000 - 1005	Opening act	Jack Buckskin
1010 - 1015	Welcome to Country	Jack Buckskin
1015 - 1020	Welcome to APhO	Ian Chubb AC, Patron of Australian Science Innovations
1020 - 1030	Welcome Address	Professor Fred Watson, Australia's Astronomer at Large
1030 - 1035	Official Opening of 20th Asian Physics Olympiad	Professor Caroline McMillen, Chief Scientist for South Australia
1035 - 1040	Acknowledgement of sponsors and supporters and overview of the week ahead	Ben Kremer, Chair of ASI
1040 - 1050	Team Introduction	Dr Paul Willis- MC
1050 - 1100	Performance	Cheryl Bradley Dance Troupe
1100	Close	Dr Paul Willis - MC
1100 - 1200	Lunch	

Closing Ceremony

Date: Sunday 12 May 2019

Time: 1530 – 1730

Location: Adelaide Convention Centre

Time	Function	Talent
1530 - 1540	Opening Performance	Festival Statesman
1540 - 1545	Welcome and introduce video highlights package	Dr Paul Willis
1545 -1555	Closing Address	David Pisoni MP SA Minister for Innovation and Skills
1555 - 1605	Results introduction speech	Dr Matt Verdon, Chair APhO Academic Committee
1605 - 1655	Medal Presentation	Dr Paul Willis
1605 - 1615	Gold Medallists announced	Dr Matt Verdon
1615 - 1625	Silver Medallists announced	Dr Bonnie Zhang
1625 - 1635	Bronze Medallists announced	Dr Alix Verdon
1635 - 1645	Honourable Mention announced	Professor Vyacheslavs Kascheyevs
1645 - 1655	Special Award students announced	Dr Matt Verdon
1655 - 1705	APhO 2019 Wrap up and acknowledgements	Ruth Carr, Executive Director Australian Science Innovations
1705 - 1710	Introduction of 2020 host country	Professor Kwek – President of Asian Physics Olympiad Professor Chih-Ta Chia, 2020 APhO Organising Committee
1710 - 1720	Performance	Kuma Kaaru Dance
1720 - 1730	Close	Dr Paul Willis
1730	Closing video- Video montage playing as guests exit	
1730 - 1800	Official Photos in foyer	
1800 - 2200	Final Dinner	

Asian Physics Olympiad
Adelaide, Australia | 5–13 May 2019

Problems and Solutions

General instructions: Theoretical Examination (30 points)

May 7, 2019

The theoretical examination lasts for 5 hours and is worth a total of 30 points.

Before the exam

- You must not open the envelopes containing the problems before the sound signal indicating the beginning of the competition.
- The beginning and end of the examination will be indicated by a sound signal. There will be announcements every hour indicating the elapsed time, as well as fifteen minutes before the end of the examination (before the final sound signal).

During the exam

- Dedicated answer sheets are provided for writing your answers. Write your answers into the appropriate tables, boxes or graphs on the corresponding answer sheet (marked A). For every problem, there are extra blank working sheets for carrying out detailed work (marked W). Be sure to always use the working sheets that belong to the problem you are currently working on (check the problem number in the header). If you have written something on any sheet which you do not want to be graded, cross it out. Only use the front side of every page.
- In your answers, try to be as concise as possible: use equations, logical operators and sketches to illustrate your thoughts whenever possible. Avoid the use of long sentences.
- Please give an appropriate number of significant figures when stating numbers.
- Often, you may be able to solve later parts of a problem without having solved the previous ones.
- A list of physical constants is given on the next page.
- You are not allowed to leave your working place without permission. If you need any assistance, please draw the attention of a team guide by raising one of your flags ("I need water" if you need water, "toilet break" if you need to go to the toilet, "Extra paper, please!" if you need extra working sheets, "equipment/materials" if you have a problem with your equipment or materials or "I need help" in all other cases).

At the end of the exam

- At the end of the examination you must stop writing immediately.
- For every problem, sort the corresponding sheets in the following order: cover sheet (C), questions (Q), answer sheets (A), working sheets (W) and then extra sheets (Z) if you have them.
- Put all the sheets belonging to one problem into the envelope for that question. Also put the general instructions (G) into the remaining separate envelope. Also hand in empty sheets. You are not allowed to take any sheets of paper out of the examination area.
- Leave your writing equipment on the table, you will use it again in the experimental exam.
- Wait at your table in silence until your envelopes are collected. Once all envelopes are collected your guide will escort you out of the examination area.

General Data Sheet

Speed of light in vacuum	c	$=$	$299\ 792\ 458\ \mathrm{m \cdot s^{-1}}$
Vacuum permeability	μ_0	$=$	$4\pi \times 10^{-7}\ \mathrm{kg \cdot m \cdot A^{-2} \cdot s^{-2}}$
Vacuum permittivity	ε_0	$=$	$8.854\ 187\ 817 \ldots \times 10^{-12}\ \mathrm{A^2 \cdot s^4 \cdot kg^{-1} \cdot m^{-3}}$
Elementary charge	e	$=$	$1.602\ 176\ 620\ 8(98) \times 10^{-19}\ \mathrm{A \cdot s}$
Mass of the electron	m_e	$=$	$9.109\ 383\ 56(11) \times 10^{-31}\ \mathrm{kg}$
Mass of the proton	m_p	$=$	$1.672\ 621\ 898(21) \times 10^{-27}\ \mathrm{kg}$
Mass of the neutron	m_n	$=$	$1.674\ 927\ 471(21) \times 10^{-27}\ \mathrm{kg}$
Atomic mass constant	m_u	$=$	$1.660\ 539\ 040(20) \times 10^{-27}\ \mathrm{kg}$
Rydberg constant	R_∞	$=$	$10\ 973\ 731.568\ 508(65)\ \mathrm{m^{-1}}$
Universal constant of gravitation	G	$=$	$6.674\ 08(31) \times 10^{-11}\ \mathrm{m^3 \cdot kg^{-1} \cdot s^{-2}}$
Acceleration due to gravity in Adelaide	g	$=$	$9.797\ \mathrm{m \cdot s^{-2}}$
Planck's constant	h	$=$	$6.626\ 070\ 040\ (81) \times 10^{-34}\ \mathrm{kg \cdot m^2 \cdot s^{-1}}$
Avogadro number	N_A	$=$	$6.022\ 140\ 857\ (74) \times 10^{23}\ \mathrm{mol^{-1}}$
Molar gas constant	R	$=$	$8.314\ 4598(48)\ \mathrm{kg \cdot m^2 \cdot s^{-2} \cdot mol^{-1} \cdot K^{-1}}$
Molar mass constant	M_u	$=$	$1 \times 10^{-3}\ \mathrm{kg \cdot mol^{-1}}$
Boltzmann constant	k_B	$=$	$1.380\ 648\ 52(79) \times 10^{-23}\ \mathrm{kg \cdot m^2 \cdot s^{-2} \cdot K^{-1}}$
Stefan-Boltzmann constant	σ	$=$	$5.670\ 367\ (13) \times 10^{-8}\ \mathrm{kg \cdot s^{-3} \cdot K^{-4}}$

RF reflectometry for spin readout for silicon quantum computing

Introduction

Developing the idea of quantum computing into a practical technology is one of the largest outstanding challenges in science and technology. A promising path is to manipulate individual electrons in silicon transistors by time-dependent electromagnetic fields.

In this question, we investigate the use of radio frequency (RF) reflectometry and single-electron transistors to read out the state of quantum bits in silicon-based quantum computer prototypes.

Part A and Part B discuss radio wave transmission through cables and transmission lines, part C is devoted to conditions for wave reflection, part D introduces the single-electron transistor, and parts E and F introduce and ask you to optimise the method of reflectometry.

Part A: Lumped element model of a co-axial transmission line (2.0 points)

When modelling DC or low frequency signals, one often assumes that a voltage pulse travels instantaneously throughout the circuit. This assumption is valid when the wavelength of such signals is much longer than the size of the circuit, however when working with radio frequency signals, the dynamics are more complex, and we need to account for the intrinsic capacitance and inductance of our cables in our model. We model a co-axial transmission line which acts as a waveguide as described below, ignoring the small resistance of the copper and the small conductance through the dielectric. Throughout the problem, we consider the large-wavelength limit of electromagnetic waves in the co-axial cable such that electric and magnetic fields are perpendicular to the axis of the cable everywhere (the so-called transverse electromagnetic mode).

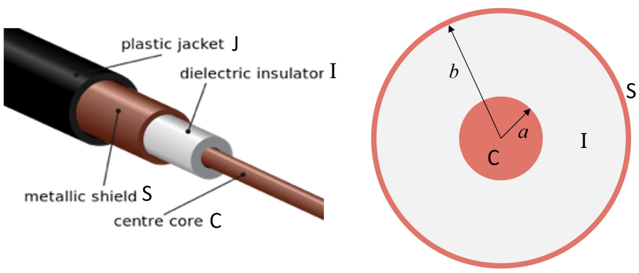


Diagram of a coaxial cable showing C - the centre core, I - the dielectric insulator, S - the metallic shield and J - the plastic jacket.

Consider a co-axial cable consisting of a copper inner core of negligible resistance, negligible magnetic permeability and radius a, covered by an outer co-axial copper shield with inner radius b. A dielectric of dimensionless relative permittivity ε_{r} and dimensionless relative permeability μ_{r} separates the layers. When electromagnetic signals propagate through the co-axial cable, they are confined between the inner core and outer shielding.

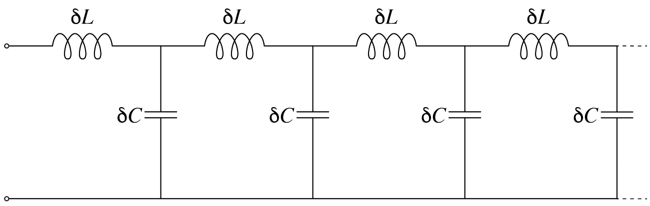
A.1	At what speed do electromagnetic waves propagate in the co-axial cable?	0.2pt

A.2	If there is a charge Δq on a length Δx of the inner core of the co-axial cable, and the outer shield is grounded, find the electric field in the region between the inner core and the shield.	0.2pt

A.3	Find the capacitance per unit length, C_x, of the co-axial cable. You may wish to consider a length Δx of the cable.	0.3pt

A.4	Find the inductance per unit length, L_x, of the cable.	0.3pt

A *lumped element* model of the cable is constructed by considering the inductance and capacitance of short sections of the cable. The inductance is assumed to be a property of the inner core, and the capacitance links the core with the shielding. A diagram of the lumped element model is shown below.



Circuit diagram of lumped element model of coaxial cable.

A.5	i. Show that the impedance Z_0 of a semi-infinite length of cable is $Z_0 = \sqrt{L_x/C_x}$. ii. Find b/a if the cable has impedance $Z_0 = 50\ \Omega$ and is made using a dielectric material with $\varepsilon_r = 4.0$ and $\mu_r = 1.0$.	1.0pt

Part B: Hypothetical transmission line with return along a grounded plane (1.0 points)

An alternative hypothetical transmission line is shown in the diagram below. The input signal is sent through a very thin conductor of radius a, which is a distance $d \gg a$ from a highly conductive grounded plane. The material surrounding the conductor has dimensionless relative permittivity ε_r and dimensionless relative permeability μ_r. The return current flows along the grounded plane.

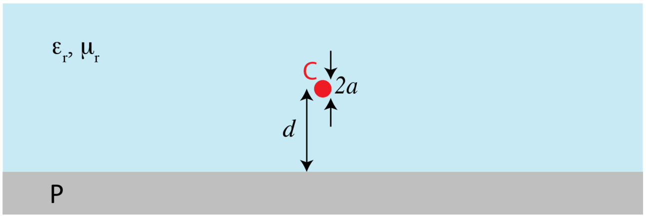


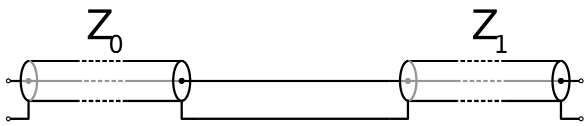
Diagram of a hypothetical transmission line showing C - the conductor of radius a, at a distance $d \gg a$ from P - the grounded conducting plane. The conductor is embedded in a material with dimensionless relative permeability ε_r and dimensionless relative permittivity μ_r.

B.1	Find an expression for the characteristic impedance of this hypothetical transmission line.	1.0pt

Part C: Basics of RF reflectometry (1.2 points)

An electromagnetic wave can propagate in a transmission line in two opposite directions. For each direction of propagation, the characteristic impedance Z_0can be used to relate the voltage V_0 and current I_0amplitudes as in the Ohm's law, $Z_0 = V_0/I_0$.

Consider an interface between two transmission lines, with characteristic impedances Z_0 and Z_1. A schematic diagram of the circuit is shown below.



Circuit diagram of a transmission line of impedance Z_0 connected to a transmission line of impedance Z_1. The physical size of the interface is much smaller than the wavelength.

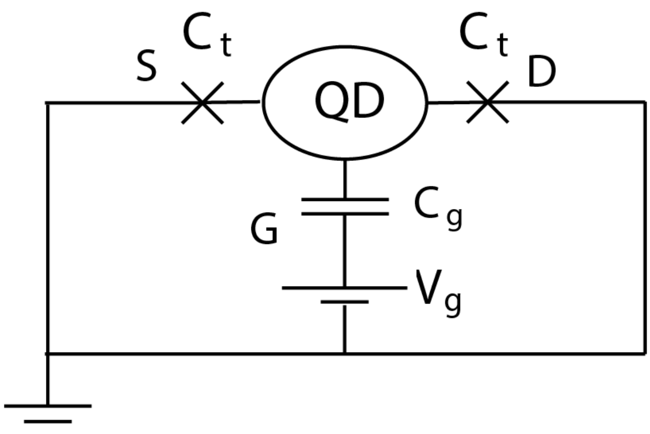
When a signal V_i sent into the transmission line with impedance Z_0reaches the interface it is partially transmitted into the second transmission line, resulting in a signal V_t in that line which propagates forward. Some of the signal may also be reflected, resulting in a backward propagating signal in the initial transmission line V_r.

C.1	Find the reflectance of the interface $\Gamma = V_r/V_i$.	1.0pt

C.2	State the condition(s) for the signal V_i to have gained a π phase change on reflection.	0.2pt

Part D: The single electron transistor (3.3 points)

A single electron transistor (SET) consists of a quantum dot, which is a small isolated conductor where electrons can be localised, and of several electrodes in its vicinity. The gate electrode couples capacitatively to the quantum dot, while the two other electrodes --- the source and the drain --- are connected via tunnel junctions, through which electrons can tunnel due to quantum mechanics. A simplified circuit diagram for an SET is shown in the figure.



Circuit diagram representation of an SET. QD is the quantum dot, S is the source, D is the drain and G is the gate.

The capacitance of the gate is C_g and the capacitance of the tunnel junctions is $C_t \ll C_g$. Consider C_g to be the total capacitance of the quantum dot. In this part of the problem, the source and the drain are held at zero potential, and the voltage on the gate electrode is fixed at V_g.

D.1	Consider a state of the SET in which the quantum dot contains n electrons. i. Find the electrical potential φ_n on the QD. ii. Find the amount of energy ΔE_n that is necessary to bring an additional electron from the source or the drain onto the QD.	1.5pt

If $\Delta E_n < 0$ then electrons will spontaneously tunnel into the quantum dot until such a number $\mathcal{N} > n$ is reached that $\Delta E_{\mathcal{N}} \geq 0$. The equilibrium number of electrons $\mathcal{N}$ and the corresponding addition energy $\Delta E_{\mathcal{N}}$ can be controlled by choosing the appropriate voltage V_g.

D.2	Find an expression for the maximal possible value $E_c = \max \Delta E_{\mathcal{N}}(V_g)$ of the equilibrium addition energy that can be achieved by tuning the gate voltage of the SET.	0.5pt

If $\Delta E_{\mathcal{N}} = 0$ then tunnelling of electrons does not require extra energy and SET is in a highly conductive ON state. If $\Delta E_{\mathcal{N}} > 0$, then the conductance of the SET is reduced (high-resistance OFF).

For the number of electrons on the quantum dot to remain well-defined, certain conditions need to be satisfied. Firstly, if electrons in the source or drain have thermal energies sufficient to move spontaneously onto the quantum dot, the contrast between the ON and OFF states will disappear.

D.3	Find a condition on the temperature of the electrons so that electrons cannot move onto the quantum dot by thermal excitation.	0.5pt

Secondly, tunnelling of electrons onto or off the dot limits the lifetime of their energy states. This tunnelling can be modelled using an effective resistance of the tunnel junction with the characteristic tunnelling time equal to the characteristic time for charging or discharging the quantum dot through the junction.

D.4	i. Estimate the tunnelling time for a quantum dot in terms of capacitance C_t and effective resistance R_t of the tunnel junction. ii. Find a condition on the effective resistance R_t so that the electrons in the quantum dot retain sufficiently well-defined energy for the ON and OFF states to remain distinct.	0.8pt

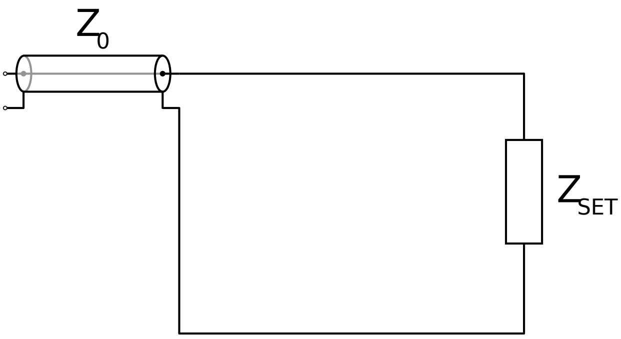
Part E: RF reflectometry to read out SET state (1.0 points)

The state of the SET is sensitive to electrical potentials created by nearby elements of the quantum circuit (such as quantum bits), and distinguishing between ON and OFF states provides a way to read out the information produced by the quantum computer. The SET in the ON state can be modelled by a resistance $R_{\text{ON}} = 100\,\text{k}\Omega$ while in the OFF state we can assume the SET to be a complete insulator (neglecting any capacitative connection between the source and the drain via the SET). While it is possible to determine the state of the SET by measuring the response to an input signal through the source, it is faster to do so using RF reflectometry to measure both the amplitude and phase of the reflected signal, i.e. determined the reflectance Γ.

The change in reflectance due to switching of an SET between ON and OFF states is

$$\Delta\Gamma = |\Gamma_{\mathrm{ON}} - \Gamma_{\mathrm{OFF}}| \ , \tag{1}$$

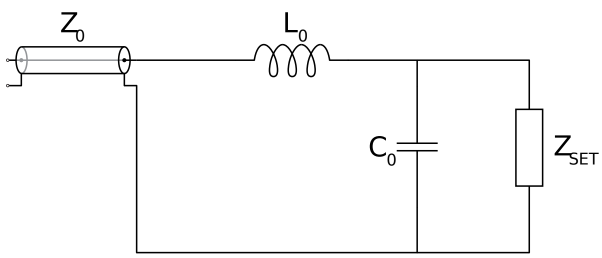
where Γ_{ON} and Γ_{OFF} are the reflectances in two different states.



Circuit diagram of transmission cable of impedance Z_0 connected to an SET.

E.1	Find the change in reflectance $\Delta\Gamma$ between the conductive and insulating states for a typical SET connected to a co-axial cable with impedance of $50\ \Omega$.	0.2pt

In order to increase the change in reflectance, and hence the sensitivity of the RF reflectometry, the circuit is modified by inclusion of an inductor. The intrinsic capacitance due to the device geometry $C_0 \approx 0.4\ \mathrm{pF}$ is also taken into account. The RF reflectometry is conducted using a signal of angular frequency ω_{rf}.



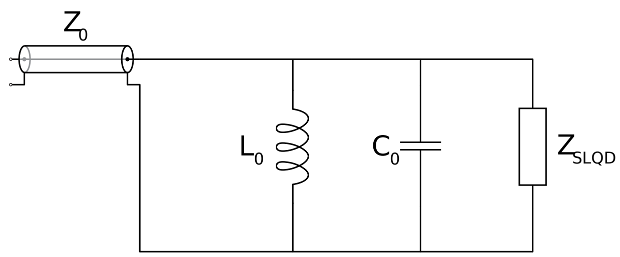
Modified SET circuit.

E.2	Estimate the value of the inductance L_0 that can result in the change in reflection on the order of one. Calculate your estimate for L_0 numerically for $\omega_{\mathrm{rf}}/(2\pi) = 100\,\mathrm{MHz}$ and compute the corresponding $\Delta\Gamma$.	0.8pt

Part F: Charge sensing with a single lead quantum dot (1.5 points)

For a scalable quantum computing architecture, the number of wires reaching each individual quantum bit need to be minimized. A promising alternative to an SET for charge sensing in silicon quantum computing is a Single Lead Quantum Dot (SLQD). In many ways it is similar to an SET, but does not have the source and drain leads. The gate is the only electrode, through which the electron energy states of the quantum dot are controlled and also through which RF reflectometry is conducted.

Like an SET, a SLQD has an OFF in which the SLQD behaves as a total insulator. In contrast to an SET, the ON state of the SLQD is capacitive, with capacitance C_q. In order to maximize the difference in reflectance $\Delta\Gamma$ of the SLQD, the following circuit is constructed. The parasitic capacitance $C_0 \approx 0.4\,\mathrm{pF}$ is fixed by circuit geometry, but the value of L_0 and the operating frequency can be changed to optimize the performance. The characteristic impedance of the transmission line is $Z_0 = 50\,\Omega$.



Circuit diagram of the SLQD readout circuit connected to the transmission line.

F.1	Suggest ω_rf and $Z_\mathrm{C} = \sqrt{L_0/C_0}$ that allow $\Delta\Gamma \sim 1$ for given C_0 and C_q.	1.0pt

Optimal values of L_0 are relatively large and not always technically feasible. Hence, other types of circuit elements may be needed to improve sensitivity of the reflectometry readout circuit.

F.2	Assume that L_0 (and hence Z_C) is fixed. Draw a circuit diagram showing where to place an additional element in the SLQD readout circuit and specify the parameter(s) of this element such that $\Delta\Gamma \sim 1$ can still be achieved without requiring a large inductance.	0.5pt

RF Reflectometry of Single-Electron Circuits

Part A: Lumped element model of a co-axial transmission line (2.0 points)

A.1 (0.2 pt)

$v =$

A.2 (0.2 pt)

$E(r) =$

A.3 (0.3 pt)

$C_x =$

A.4 (0.3 pt)

$L_x =$

A.5 (1.0 pt)

i.

ii. $b/a =$

Part B: Hypothetical transmission line with return along a grounded plane (1.0 points)

B.1 (1.0 pt)

$Z_0 =$

Part C: Basics of RF reflectometry (1.2 points)

C.1 (1.0 pt)

$\Gamma =$

C.2 (0.2 pt)

Part D: The single electron transistor (points 3.3)

D.1 (1.5 pt)

i. $\varphi_n =$

ii. $\Delta E_n =$

D.2 (0.5 pt)
$E_c =$

D.3 (0.5 pt)

D.4 (0.8 pt)
i. $\tau =$
ii.

Part E: RF reflectometry to read out SET state (1.0 points)

E.1 (0.2 pt)
$\Delta\Gamma =$

E.2 (0.8 pt)
$L_0 =$
$\Delta\Gamma =$

Part F: Charge sensing with a single lead quantum dot (1.5 points)

F.1 (1.0 pt)
$\omega_{\mathrm{rf}} =$
$Z_C =$

F.2 (0.5 pt)

X-ray jets from active galactic nuclei

Introduction

Active galactic nuclei (AGN) are supermassive black holes which form the centres of galaxies, and emit large amounts of energy in radiation and particle flows. One feature of many AGN are jetted outflows, which can be observed through radio emission, and sometimes also in other parts of the electromagnetic spectrum, including x-rays. These jets are large flows of plasma at relativistic speeds, over lengths of order 10^{20} m, which is tens of thousands of light years. The x-ray emission from jets is usually dominated by synchrotron emission from relativistic electrons gyrating in the magnetic field of the jet.

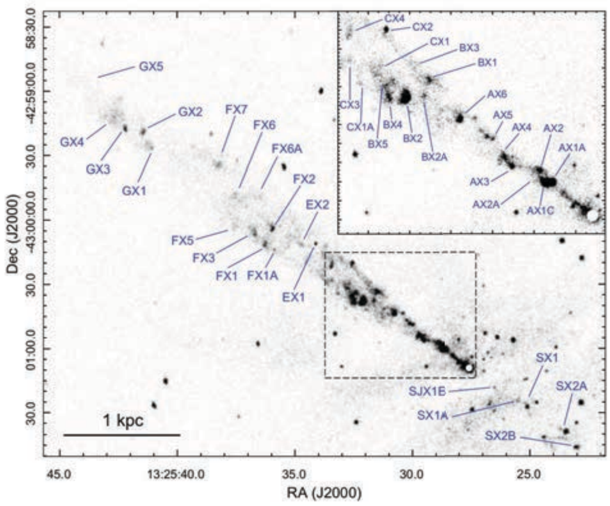


Figure 1: X-ray image of the jet from the Centaurus A AGN. Darker regions represent regions of higher intensity x-rays. Brighter regions within the fainter jet are called knots. (Snios *et al.*, 2019)

Part A: 1D fluid model of a jet

A simple model of the flow of jets assumes that the flow is steady and directed radially away from the central AGN, so approximately one dimensional, and that the plasma in the jet is in pressure equilibrium with its surroundings. There is assumed to be a constant rate per volume of mass injected into the jet from stars which lose their outer layers as they move through their life cycle.

The jet is described in terms of the coordinate representing distance from the AGN, s, and the opening radius r of the conical jet. These distances are measured in parsecs, where $1\ \mathrm{pc} = 3.086 \times 10^{16}\ \mathrm{m}$. The speed of the jet flow is assumed to be directed radially away from the central AGN, and be a function of s only. The plasma in the jet is comprised of electrons, protons, and some heavier ionised nuclei. The average energy carried by each particle in the jet, in the reference frame of the bulk flow of the jet (which we will call the jet frame), is $\epsilon_{\mathrm{av}} = \mu_{\mathrm{pp}} c^2 + h$, where the term h includes all thermal kinetic energy and potential energies in terms of the pressure P and n is the number density of the plasma.

As the stars, which the jet flows past, move through their life cycles they can lose part of their atmosphere. This results in a uniform rate of injection of mass per unit volume α into the jet, and the injected particles are assumed to be at rest relative to the AGN.

This model can be applied to the Centaurus A jet. Centaurus A is one of the nearest AGN, so it is possible to observe its jet at relatively high spatial resolution. The total power carried by the jet is estimated to be $P_{\mathrm{j}} = 1 \times 10^{36}$ J.s^{-1}. See below for a diagram of a simple geometrical description of the Centaurus A jet, including measurements of some jet parameters. s_1 is the coordinate of the start of the jet, and s_2 the coordinate of the end of the jet. In Centuarus A the average mass per particle is $\mu_{\mathrm{pp}} = 0.59 m_{\mathrm{p}}$ and $h = \frac{13}{4} P/n$ .The pressure in the plasma surrounding the jet is $P(s) = 5.7 \times 10^{-12} \left(\frac{s}{s_0}\right)^{-1.5}$ Pa, where $s_0 = 1$ kpc.

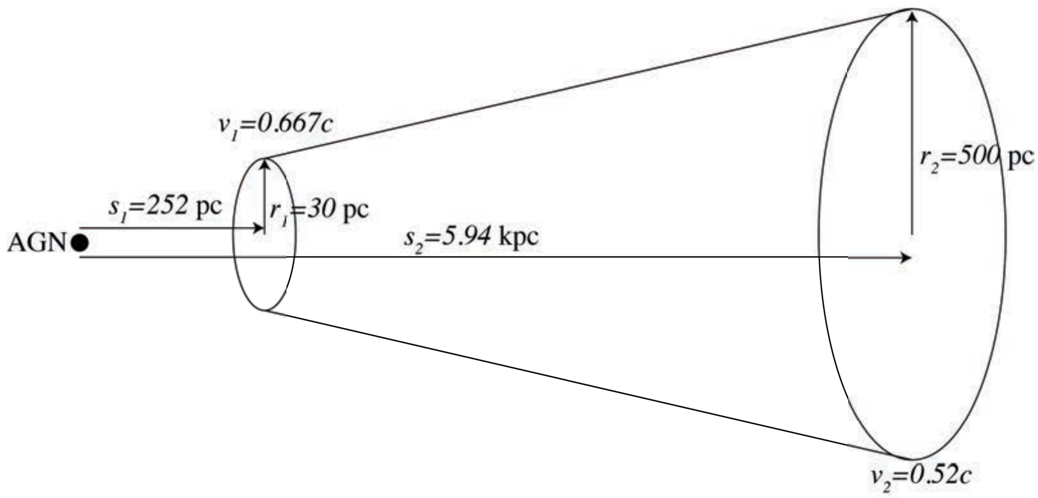


Figure 2: The Centaurus A jet, showing the geometry compared to the active galactic nucleus (AGN).

The jet is described by the following parameters, all of which depend on the distance s from the AGN:

- the opening radius of the jet $r(s)$ in the AGN frame
- the cross sectional area of the jet $A(s)$ in the AGN frame
- the speed of the jet $v(s)$ in the AGN frame
- the lorentz gamma factor of the jet $\gamma(s)$ in the AGN frame
- the number density $n(s)$ in the frame of the jet

Any of these parameters can be used in your answers to A1-4.

A.1	Find the number density of particles, $n'(s)$, in the frame of the AGN, in terms of the proper number density, $n(s)$ and other jet parameters. The proper number density is the number density in the frame which is locally co-moving with the jet plasma outflow, which we will call the jet frame.	0.3pt

A.2	Find the flux of particles, $F_p(s)$, across a cross section of the jet with area A, at a distance s from the AGN.	0.2pt

A.3	Write a continuity relationship between the particle flux into the jet and out of the jet in terms of the jet parameters at s_1 and s_2, and V, the total volume of the Centaurus A jet and other required parameters.	0.5pt

A.4	Write a relationship between the energy flux into the jet, and the energy flux out of the jet in terms of the jet speeds, cross sectional areas and proper number densities at $s_1$and s_2, the volume, V, of the jet and any other required parameters of the Centaurus A jet.	0.6pt

The power carried by a jet is defined to be the sum of the total bulk kinetic energy flux and the total thermal energy flux, so

$$P_{\mathrm{j}}(s) = F_{\mathrm{E}}(s) - \dot{M}c^2 \tag{1}$$

where $F_{\mathrm{E}}(s)$ is the flux of energy through the cross section of the jet at s, and $\dot{M}$ is the mass flux through the jet cross section at the same distance s from the AGN.

A.5	Using your answers to previous parts find $\frac{dP_{\mathrm{j}}}{ds}$.	0.6pt

A.6	Find numerical values for the mass fluxes $\dot{M}_1$, into the Centaurus A jet at s_1, and also $\dot{M}_2$, out of the Centaurus A jet at s_2,	0.4pt

A.7	Find an expression for the total momentum flux, Π, into the Centaurus A jet. Also numerically evaluate this expression.	0.5pt

A.8	Find a numerical value for the total force due to external pressure, F_{Pr}, on the Centaurus A jet.	0.5pt

A.9	Write the expected relationship between Π and F_{Pr}. Also, calculate the percentage difference between the model value of Π , which you found in A7, and the expected value.	0.2pt

Part B: Gas of ultra relativistic electrons

Consider a gas of ultra relativistic electrons ($\gamma \gg 1$), with an isotropic distribution of velocities (does not depend on direction). The proper number density of particles with energies between ϵ and $\epsilon + d\epsilon$ is given by $f(\epsilon)d\epsilon$, where ϵ is the energy per particle. Consider also a wall of area ΔA, which is in contact with the gas.

B.1	Write an integral expression for the total energy per volume of the electron gas.	0.2pt

B.2	Find an expression for the total rate of change in momentum $\Delta p_z/\Delta t$ of the gas, in the z-direction which is normal to the wall, due to collisions with the wall.	0.8pt

B.3	Derive an equation of state for an ultra relativistic electron gas, relating the pressure, volume and total internal energy.	0.6pt

B.4	Derive a relationship between the pressure and volume of an ultra relativistic electron gas undergoing an adiabatic expansion.	0.6pt

Part C: Synchrotron emission

In the jets from AGN, we have populations of highly energetic electrons in regions with strong magnetic fields. This creates the conditions for the emission of high fluxes of synchrotron radiation. The electrons are often so highly energetic, that they can be described as ultra relativistic with $\gamma \gg 1$.

C.1	Find an expression for Ω, the angular frequency of gyration of an electron with lorentz factor γ and travelling at an angle ϕ to the magnetic field B.	0.7pt

As the electron is accelerated due to the magnetic field it emits electromagnetic radiation. In a frame at which the electron is momentarily at rest, there is no preferred direction for the emission of the radiation. Half is emitted in the forward direction, and half in the backward direction. However, in the frame of the observer, for an electron moving at an ultra relativistic speed, with $\gamma \gg 1$, the radiation is concentrated in a forward cone with $\theta \lesssim 1/\gamma$ (so the total angle of cone is $2/\gamma$). As the electron is gyrating around the magnetic field, any observer will only see pulses of radiation as the forward cone sweeps through the line of sight.

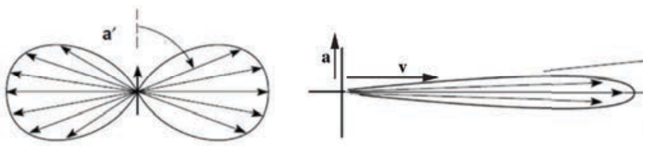


Figure 3: The diagram on the left shows the distribution of power in radiation from an electron accelerating up the page in the frame at which the electron in momentarily at rest. The diagram on the right shows the distribution of power in radiation for the same electron in the observer's frame, where most radiation is emitted in the forward cone. In the observers frame, the direction of the electron's acceleration is shown by a vector labelled **a** and the direction of its velocity is shown by a vector labelled **v**.

C.2	Find the duration of a pulse, Δt, of synchrotron radiation observed from an electron with lorentz factor γ, travelling at an angle ϕ to the magnetic field.	0.5pt

C.3	Hence, estimate the characteristic frequency, ν_{chr}, of the synchrotron radiation.	0.3pt

The total synchrotron power emitted is

$$P_{\mathrm{s}} = \frac{1}{6\pi\varepsilon_0}\left(\frac{q^4 B^2 \sin^2\phi}{m^4 c^5}\right) E^2 \tag{2}$$

C.4	Estimate the time, τ, for an electron of energy E to lose its energy through synchrotron cooling.	0.2pt

Part D: Synchrotron emission from an AGN jet

The distribution of electron energies in a jet from an AGN is typically a power law, of the form $f(\epsilon) = \kappa\epsilon^{-p}$, where $f(\epsilon)d\epsilon$ is the number density of particles with energies between ϵ and $\epsilon + d\epsilon$. The corresponding spectrum of synchrotron emission depends on the electron energy distribution, rather than the spectrum for an individual electron. This spectrum is

$$j(\nu)d\nu \propto B^{(1+p)/2}\nu^{(1-p)/2}d\nu \quad . \tag{3}$$

Here $j(\nu)d\nu$ is the energy per unit volume emitted as photons with frequencies between ν and $\nu + d\nu$

Observations of the Centaurus A jet, and other jets, show a knotty structure, with compact regions of brighter emission called knots. Observations of these knots at different times have shown both motion and brightness changes for some knots. Two possible mechanisms for the reductions in brightness are adiabatic expansion of the gas in the knot, and synchrotron cooling of electrons in the gas in knot.

The magnetic field in the plasma in the jets is assumed to be *frozen in.* Considering an arbitrary volume of plasma, the magnetic flux through the surface bounding it must remain constant, even as the volume containing the plasma changes shape and size.

D.1	For a spherical knot which expands uniformly in all directions from a volume of V_0 to a volume V, with an initial uniform magnetic field B_0 Find the magnetic field B in the expanded knot.	0.4pt

D.2	Find $f(\epsilon)$, the distribution of electron energies after adiabatic expansion of a spherical knot to a volume V on the distribution of electron energy densities, given that the knot of volume V_0 has an initial distribution of electrons $f_0(\epsilon) = \kappa_0\epsilon^{-p}$, where $f_0(\epsilon)d\epsilon$is the number density of particles with energies between $\epsilon$and $\epsilon + d\epsilon$.	1.0pt

D.3	How will synchrotron cooling affect the distribution of the electrons? After a time interval where electrons have been undergoing synchrotron cooling, will the distribution of electron energies as a function of ϵ be steeper, shallower or leave it unchanged. Justify your answer with equations, by considering two electron energies $\epsilon_1 < \epsilon_2$.	0.3pt

The table below summarises some observations of knots (brighter regions) in jets from two AGN, Centaurus A (Cen A) and M87.

AGN	Time between observations	Knot	Brightness change in x-rays	Spectral changes in x-rays	Brightness changes in other bands (e.g. UV, optical)
Cen A	15 years	AX1C	-23%	No change	No data
Cen A	15 years	BX2	-15%	No change	No data
M87	5 years	HST-1	-73%	No data	No change
M87	5 years	Knot A	-12%	No data	No change

(Data from Snios et *al.*, 2019a; 2019b.)

D.4	In the table in the answer sheet, identify the more likely cause of reduced brightness for each knot, and identify which previous part or parts support your conclusion.	0.6pt

X-ray jets from active galactic nuclei

Part A: 1D fluid model of a jet (3.8 points)

A.1 (0.3 pt)

$n'(s) =$

A.2 (0.2 pt)

$F_{\mathrm{p}}(s) =$

A.3 (0.5 pt)

A.4 (0.6 pt)

A.5 (0.6 pt)

$\frac{dP_{\mathrm{j}}}{ds} =$

A.6 (0.4 pt)
Expression for calculating $\dot{M}$:

$\dot{M}_1 =$

$\dot{M}_2 =$

A.7 (0.5 pt)
Expression:
$\Pi =$

Numerical:
$\Pi =$

A.8 (0.5 pt)

$F_{\mathrm{Pr}} =$

A.9 (0.2 pt)
Relationship:

$\%$ deviation $=$

Part B: Gas of ultra relativistic electrons (2.2 points)

B.1 (0.2 pt)

B.2 (0.8 pt)

$\frac{\Delta p_z}{\Delta t} =$

B.3 (0.6 pt)

B.4 (0.6 pt)

Part C: Synchrotron emission (1.7 points)

C.1 (0.7 pt)

$\Omega =$

C.2 (0.5 pt)

$\Delta t =$

C.3 (0.3 pt)

$\nu_{\text{chr}} =$

C.4 (0.2 pt)

$\tau =$

Part D: Synchrotron emission from an AGN jet (2.3 points)

D.1 (0.4 pt)

$B =$

D.2 (1.0 pt)

$f(\epsilon) =$

D.3 (0.3 pt)
Synchrotron cooling will make the distribution:
☐ shallower, ☐ steeper, ☐ other

D.4 (0.6 pt)

AGN	Knot	Likely cause of cooling	Question parts which support your conclusion
Cen A	AX1C	☐ synchrotron cooling ☐ adiabatic expansion ☐ neither	
Cen A	BX2	☐ synchrotron cooling ☐ adiabatic expansion ☐ neither	
M87	HST-1	☐ synchrotron cooling ☐ adiabatic expansion ☐ neither	
M87	Knot A	☐ synchrotron cooling ☐ adiabatic expansion ☐ neither	

Tippe top

Part A (10.0 points)

A Tippe top is a special kind of top that can spontaneously invert once it has been set spinning. One can model a Tippe top as a sphere of radius R that is truncated, with a stem added. It has rotational symmetry about an axis through the stem, which is at angle θ from the vertical. As shown in Figure 1(a), its centre of mass C is offset from its geometric centre O by αR along its symmetry axis. The Tippe top makes contact with the surface it rests on at point A; we assume this surface is planar, and refer to it as the floor. Given certain geometrical constraints and if spun fast enough initially, the Tippe top will tip so that the stem points increasingly downwards, until it starts to spin on in its stem, and eventually comes to a stop.

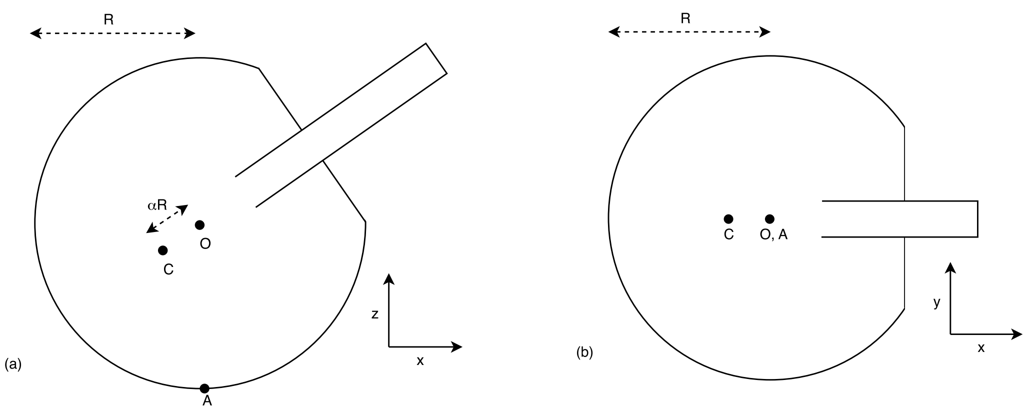


Figure 1. Views of the Tippe top (a) from the side and (b) from above

Let xyz be the rotating reference frame defined such that $\hat{\mathbf{z}}$ is stationary and upwards, and the top's symmetry axis is within the xz-plane. Two views of the Tippe top are shown in Figure 1: from the side, and from above. As shown in Figure 1(b), the top's symmetry axis is aligned with the x-axis when viewed from above.

Figure 2 shows the top's motion at several phases after it is started spinning:

(a) **phase I:** immediately after it is initially set spinning, with $\theta \sim 0$

(b) **phase II:** soon after, having tipped to angle $0 < \theta < \frac{\pi}{2}$

(c) **phase III:** when the stem first touches the floor, with $\theta > \frac{\pi}{2}$

(d) **phase IV:** after inversion, when the top is spinning on its stem, with $\theta \sim \pi$

(e) **phase V:** in its final state, at rest on its stem $\theta = \pi$.

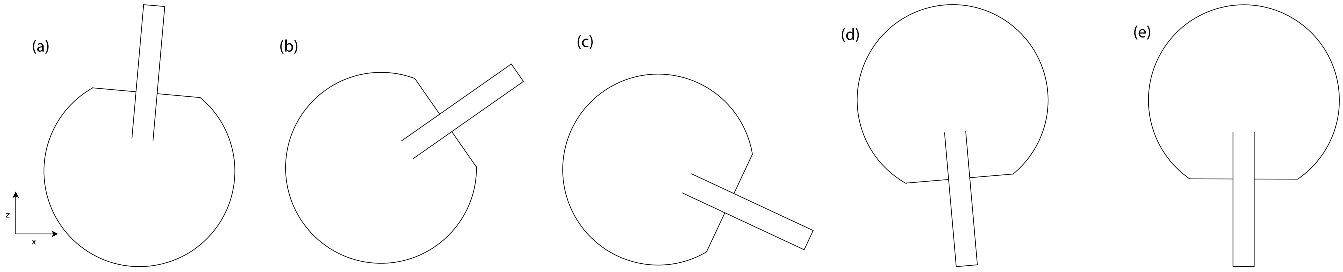


Figure 2. Phases **I** to **V** of the Tippe top's motion, shown in the xz-plane

Let XYZ be the inertial frame, where the surface the top is on is wholly in the XY-plane. The frame xyz is defined as above, and reached from XYZ via rotation around the Z axis by ϕ . The transformation from the XYZ frame to frame xyz is shown in Figure 3(a). In particular, $\hat{\mathbf{z}} = \hat{\mathbf{Z}}$.

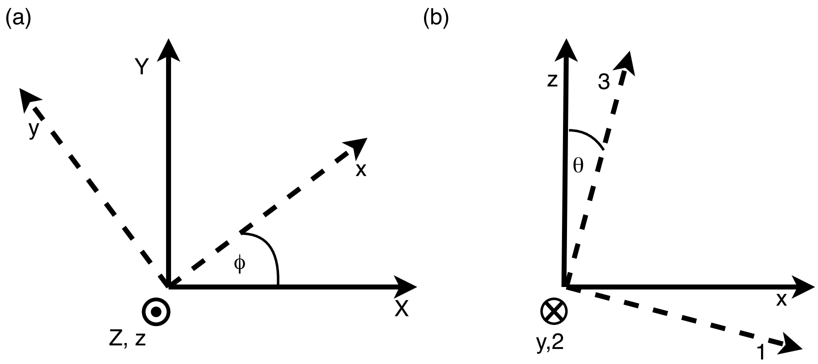


Figure 3. Transformations between reference frames: (a) to xyz from XYZ , and (b) to 123 from xyz

Any rotational motion in 3-dimensional space can be described by the three Euler angles (θ, ϕ, ψ). The transformations between the inertial frame XYZ, the intermediate frame xyz, and the top's frame 123 can be understood in terms of these Euler angles.

In our description of the Tippe top's motion, the angles θ and ϕ are the standard zenith and azimuthal angles respectively, in spherical polar coordinates. In the XYZ frame they are defined as follows: θ is the angle of the top's symmetry axis from the vertical Z-axis, representing how far from vertical its stem is, while ϕ represents the top's angular position about the Z-axis, and is defined as the angle between the XZ-plane and the plane through points $O,\ A,\ C$ (i.e. the vertical projection of the top's symmetry axis).

The third Euler angle ψ describes the rotation of the top about its own symmetry axis, i.e. its 'spin', which has angular velocity $\dot{\psi}$.

The reference frame of the spinning top is defined as a new rotating frame 123, which is reached by rotating xyz by θ around $\hat{\mathbf{y}}$: 'tilting' the $\hat{\mathbf{z}}$-axis down by θ to meet the top's symmetry axis $\hat{\mathbf{3}}$. The transformation from the xyz frame to the 123 frame is shown in Figure 3(b). In particular, $\hat{\mathbf{2}} = \hat{\mathbf{y}}$.

NOTE: For a reference frame $\widetilde{\mathbf{K}}$ rotating in inertial frame $\mathbf{K}$ with angular velocity $\boldsymbol{\omega}$, the time derivatives of a vector $\mathbf{A}$ within both frames $\mathbf{K}$ and $\widetilde{\mathbf{K}}$ are related via:

$$\left(\frac{\partial \mathbf{A}}{\partial t}\right)_{\mathbf{K}} = \left(\frac{\partial \mathbf{A}}{\partial t}\right)_{\widetilde{\mathbf{K}}} + \boldsymbol{\omega} \times \mathbf{A} \tag{1}$$

The motion that a Tippe top undergoes is complex, involving the time evolution of the three Euler angles, as well the translational velocities (or positions) and the motion of the top's symmetry axis. All of these parameters are coupled. To solve for the motion of a Tippe top, one would use standard tools including Newton's laws to prepare the system of equations, then program a computer to solve them numerically via simulation.

In this question, you will perform the first part of this process, investigating the physics of the Tippe top to set up the system of equations.

Friction between the Tippe top and the surface it is moving on drives the motion of the Tippe top. Assume that the top remains in contact with the floor at point A, until such time as the stem contacts the floor. It is in motion at point A with velocity $\mathbf{v}_A$ relative to the floor. The frictional coefficient μ_k between the top and floor is kinetic, with $|\mathbf{F_f}| = \mu_k N$, where $\mathbf{F}_f = F_{f,x}\hat{\mathbf{x}} + F_{f,y}\hat{\mathbf{y}}$ is the frictional force, and N is the magnitude of the normal force. Assume that the top is initially set spinning only, i.e. there is no translational impulse given to the top.

Let the mass of the Tippe top be m. Its moments of inertia are: I_3 about the axis of symmetry is, and $I_1 = I_2$ about the mutually perpendicular principal axes. Let $\mathbf{s}$ be the position vector of the centre of mass, and $\mathbf{a} = \overrightarrow{CA}$ be the vector from the centre of mass to the point of contact.

Unless otherwise specified, give your answers in the xyz reference frame for full marks. All torques and angular momentum are considered about the centre of mass C, unless otherwise specified. You may give your answers in terms of N. Except for part **A.8**, you need only consider the top where $\theta < \frac{\pi}{2}$, and the stem is not in contact with the floor.

A.1	Find the total external force $\mathbf{F}_{\text{ext}}$ on the Tippe top. Draw a free body diagram of the top, projected onto each of the xz- and xy-planes. Indicate the direction of $\mathbf{v}_A$ in the space provided, on your diagram in the xy-plane.	1pt
A.2	Find the total external torque $\boldsymbol{\tau}_{\text{ext}}$ on the Tippe top about the centre of mass.	0.8pt
A.3	Given the contact condition, i.e. $(\mathbf{s} + \mathbf{a}) \cdot \hat{z} = 0$, show that the velocity at A has no component in the z-direction, i.e. we can write $\mathbf{v}_A = v_x\hat{\mathbf{x}} + v_y\hat{\mathbf{y}}$.	0.4pt
A.4	Find the total angular velocity ω of the rotating top about its centre of mass C in terms of the time derivatives of the Euler angles: $\dot{\theta} = \frac{d\theta}{dt}$, $\dot{\phi} = \frac{d\phi}{dt}$, and $\dot{\psi} = \frac{d\psi}{dt}$. Use Figure 3 if this is helpful. Give your answer in the xyz frame, and in the 123 frame.	0.8pt
A.5	Find the total energy of a spinning Tippe top, in terms of time derivatives of the Euler angles, v_x, and v_y. For partial marks, you may leave your answer in terms of $\dot{\mathbf{s}} = \frac{d\mathbf{s}}{dt}$.	1pt

A.6	Find the rate of change of the angular momentum about the z-axis.	0.4pt

A.7	Which force(s) do work against gravity? Find an expression for the instantaneous rate of change of the top's energy - you may leave your answer in terms of $\mathbf{v}_A$. Identify and identify the components of the force and the torque that cause the change(s) in energy terms in **A.5**.	1.4pt

A.8	Qualitatively sketch the following energy terms in the answer sheet as a function of time, over the top's motion through the five phases **I** to **V** shown in Figure 2: the total energy E_T, gravitational potential energy U_G, translational kinetic energy K_T, and rotational kinetic energy K_R. The energy axes of your sketches are not required to be to scale.	2pt

A.9 Show that the components of the angular momentum $\mathbf{L}$ and angular velocity $\boldsymbol{\omega}$ that are perpendicular to the $\hat{\mathbf{3}}$ direction are proportional, i.e. **0.5pt**

$$\mathbf{L} \times \hat{\mathbf{3}} = k(\boldsymbol{\omega} \times \hat{\mathbf{3}}), \tag{2}$$

and find the proportionality constant k.

Combining your answers to **A.1** and **A.2** with subsequent results will give you the magnitude N of the normal force, as well as a system of equations, relating the Euler angles, the components v_x and v_y of the velocity at A, the unit vector for the axis of symmetry $\hat{\mathbf{3}}$, and their time derivatives. This system is not integrable, but instead could be solved numerically.

Integrals of motion are quantities which remain constant, and can reduce the dimensionality of the system (i.e. number of simultaneous equations to solve, whether analytically or numerically). Typically quantities such as energy, momentum, and angular momentum are conserved in closed systems, and significantly simplify the problem.

A.10 As you have seen, neither the energy nor the angular momentum are conserved for a Tippe top, due to a dissipative force and external torque. However, there is a related quantity known as Jellett's integral λ, which represents a component of the angular momentum that is conserved, i.e. some vector $\mathbf{v}$. such that $\lambda = \mathbf{L} \cdot \mathbf{v}$ is constant in time. **1.7pt**

Use your understanding of the Tippe top and results found to far, to give an expression for such a vector $\mathbf{v}$. Show that the time derivative of λ is zero.

Tippe top

Part A (10.0 points)

A.1 (1.0 pt)

$\mathbf{F}_{\text{ext}} =$

A.2 (0.8 pt)

$\tau_{\text{ext}} =$

A.3 (0.4 pt)

A.4 (0.8 pt)

$\omega =$

A.5 (1.0 pt)

$E_T =$

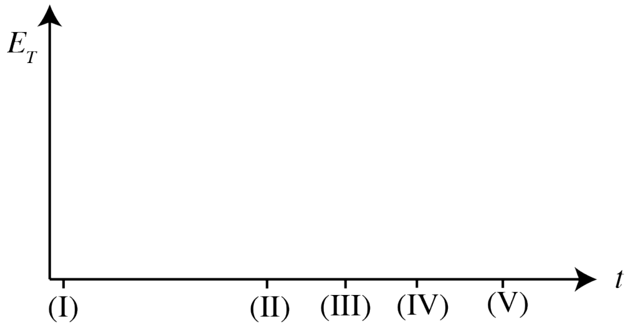
A.6 (0.4 pt)

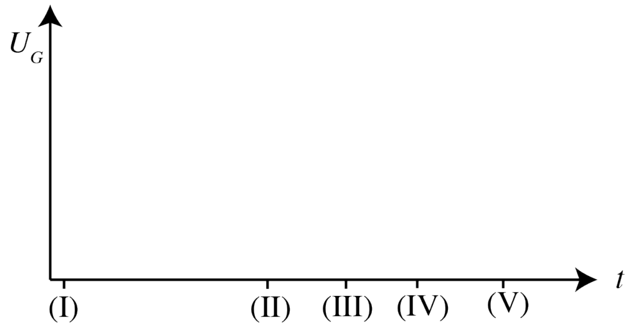
$\frac{dL_z}{dt} =$

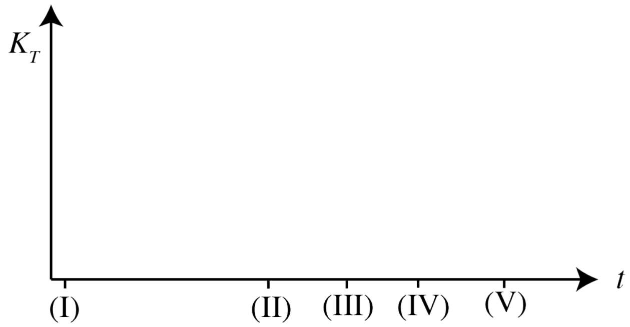
A.7 (1.4 pt)

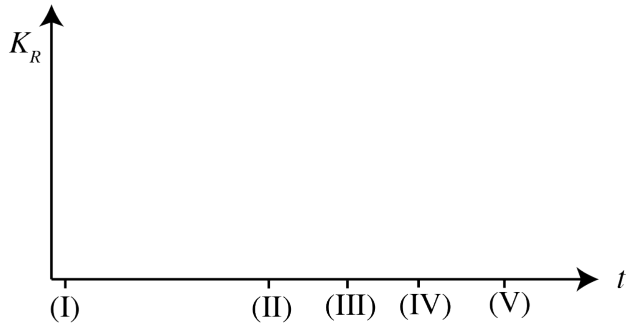
$\frac{dE_T}{dt} =$

A.8 (2.0 pt)









A.9 (0.5 pt)

$k =$

A.10 (1.7 pt)

$\mathbf{v} =$

Version 1.32.

A. LUMPED ELEMENT MODEL OF A CO-AXIAL TRANSMISSION LINE

A.1 The speed of wave propagation in free space ($c_0 = 299\,792\,458\,\mathrm{m/s}$) is $c_0 = 1/\sqrt{\varepsilon_0\,\mu_0}$. The speed in the dielectric & diamagnetic medium is

$$\boxed{v = \frac{c_0}{\sqrt{\varepsilon_\mathrm{r}\,\mu_\mathrm{r}}}} \tag{A.1}$$

A.2 Gauss law for the flux through a cylindrical surface with radius r co-axial with the the core, $a < r < b$:

$$\Delta x\, 2\pi r\, E(r) = \frac{\Delta q}{\varepsilon_\mathrm{r}\varepsilon_0} \Rightarrow E(r) = \frac{\Delta q}{\Delta x}\frac{1}{2\pi\varepsilon_\mathrm{r}\varepsilon_0 r} \tag{A.2}$$

A.3 The capacitance

$$C_x\,\Delta x = \frac{\Delta q}{\varphi} \tag{A.3}$$

where the potential φ of the core with respect to the shield is

$$0 - \varphi = -\int_a^b E(r)\,dr \Rightarrow \varphi = \frac{\Delta q}{\Delta x}\frac{1}{2\pi\varepsilon_\mathrm{r}\varepsilon_0}\ln\frac{b}{a} \tag{A.4}$$

$$\boxed{C_x = \frac{2\pi\varepsilon_\mathrm{r}\varepsilon_0}{\ln\frac{b}{a}}} \tag{A.5}$$

A.4 The magnetic flux through a rectangular contour paralel to the axis equal inductance times the current:

$$\Delta x\int_a^b B(r)\,dr = L_x\,\Delta x\, I \tag{A.6}$$

Biot-Savart law $B(r) = \frac{\mu_\mathrm{r}\mu_0}{2\pi}\frac{I}{r}$ gives

$$\boxed{L_x = \frac{\mu_\mathrm{r}\mu_0}{2\pi}\ln\frac{b}{a}} \tag{A.7}$$

A.5 i. Adding δx length of the cable should not change its impedance. Hence the impedance Z of the following circuit must be equal to Z_0:

$$\frac{1}{Z} = \frac{1}{Z_0 + j\omega\delta L} + \frac{1}{\frac{1}{j\omega\delta C}} = \frac{1}{Z_0} \tag{A.8}$$

$$Z_0^2 + j\,\omega\,\delta L\,Z_0 - \delta L/\delta C = 0 \tag{A.9}$$

(here engineering notation for $j^2 = -1$ is used.) $\delta L/\delta C = L_x/C_x$ and $\delta L \to 0$ for $\delta x \to 0$, hence

$$\boxed{Z_0 = \sqrt{L_x/C_x}} \tag{A.10}$$

ii.

$$Z_0 = \sqrt{L_x/C_x} = \frac{\ln(b/a)}{2\pi}\sqrt{\frac{\mu_\mathrm{r}\mu_0}{\varepsilon_\mathrm{r}\varepsilon_0}} = \ln(b/a)\sqrt{\frac{\mu_\mathrm{r}}{\varepsilon_\mathrm{r}}}\times 59.96\,\Omega \tag{A.11}$$

For $Z_0 = 50\,\Omega$, $\varepsilon_\mathrm{r} = 4.0$ and $\mu_\mathrm{r} = 1.0$ this gives $\boxed{b = 5.30\,a}$.

B. HYPOTHETICAL TRANSMISSION LINE WITH RETURN ALONG A GROUNDED PLANE

B.1 The high-conductance ground plate can be replaced by an image of the wire with opposite direction of the current at distance $2d$ from the real wire. The magnetic fields from the real and the imaginary wires add up and need to be integrated to get the magnetic flux between the wire and the plate:

$$L_x\,\Delta x\,I = \frac{\mu\mu_0}{2\pi} I \int_a^d \left(\frac{1}{r} + \frac{1}{2d-r}\right) dr\,\Delta x \tag{B.1}$$

$$L_x = \frac{\mu\mu_0}{2\pi} \ln\left(\frac{2d}{a} - 1\right) \approx \frac{\mu\mu_0}{2\pi} \ln\frac{2d}{a} \tag{B.2}$$

The potential difference between the wire and the plate can be obtained similarly by integrating the combined field for the wire and its image:

$$\varphi = \frac{\Delta q}{\Delta x} \frac{1}{2\pi\varepsilon_\mathrm{r}\varepsilon_0} \int_a^d \left(\frac{1}{r} + \frac{1}{2d-r}\right) dr = \frac{\Delta q}{\Delta x} \frac{\ln(2d/a)}{2\pi\varepsilon_\mathrm{r}\varepsilon_0} \tag{B.3}$$

$$C_x = \frac{\Delta q}{\Delta x} \frac{1}{\varphi} \approx \frac{2\pi\varepsilon_\mathrm{r}\varepsilon_0}{\ln(2d/a)} \tag{B.4}$$

Hence the characterstic impedance $Z_0 = \sqrt{L_x/C_x}$ of the wire-plate system is

$$\boxed{Z_0 = \frac{\ln(2d/a)}{2\pi}\sqrt{\frac{\mu_\mathrm{r}\mu_0}{\varepsilon_\mathrm{r}\varepsilon_0}}} \tag{B.5}$$

C. BASICS OF RF REFLECTOMETRY

C.1 At the interface, values of the voltage on both transmission lines have to coincide:

$$V_\mathrm{i} + V_\mathrm{r} = V_\mathrm{t} \tag{C.1}$$

The current has to be conserved at the interface, however, the incident and the reflected waves carry the current in opposite directions:

$$\frac{V_\mathrm{i}}{Z_0} - \frac{V_\mathrm{r}}{Z_0} = \frac{V_\mathrm{t}}{Z_1} \tag{C.2}$$

It is clear from the equation above that $V_\mathrm{t} \neq 0$ if $Z_0 \neq Z_1$ – impedance mismatch has to cause reflection. Solving the voltage and the current equations for $\Gamma = V_\mathrm{r}/V_\mathrm{i}$ gives

$$\boxed{\Gamma = \frac{Z_1 - Z_0}{Z_1 + Z_0}} \tag{C.3}$$

C.2 A π-shift implies opposite signs of V_i and V_r and hence requires $\Gamma < 0$. This implies $\boxed{Z_1 < Z_0}$.

D. THE SINGLE ELECTRON TRANSISTOR

D.1 i. Since any capacitance beyond C_g is neglected in our model, the quantum dot can be thought as a capacitor plate with the gate being the other plate of the same capacitor with capacitance C_g. The fixed number n of electrons trapped on the quantum dot sets a fixed-charge ($q = -ne$) boundary condition for the capacitor C_g on the QD, while the gate side is kept at a constant potential V_g. (We denote the elementary charge by $e > 0$). The implies that an excess charge of opposite sign, $-q = ne$ will accumulate on the gate, to keep electric field confined between the QD and the gate. The potential jump across the capacitor from the gate to the QD will be equal to the capacitor $q/C_g = -ne/C_g$. Hence the potential on the QD is

$$\boxed{\varphi_n = V_g + \frac{-ne}{C_\mathrm{g}}} \tag{D.1}$$

ii. Bringing an infinitesimal charge δq from potential 0 to potential $\varphi(q)$ requires energy $\delta E = \varphi(q)\delta q$, and the dependence of potential $\varphi(q)$ on the accumulated charge q is linear. For the single-electron transfer, the additional charge of the electron, $-e$, changes the potential from φ_n to $\varphi_{n+1} = \varphi_n - e/C_g$. Hence the work necessary to accumulate an extra e on the QD is the integral of δE

$$\Delta E_n = -e\frac{\varphi_n + \varphi_{n+1}}{2} \tag{D.2}$$

$$\boxed{\Delta E_n = \frac{e^2}{C_g}\left(n + \frac{1}{2}\right) - eV_g} \tag{D.3}$$

Alternatively, ΔE_n can be obtained from energy conservation, by computing the change of the energy of the capacitor the dork the work done against the electromotive force of the battery (=− "work done by the battery') for a charge $+e$ to be brought from the ground potential via the battery to the gate-side plate of the capacitor:

$$\Delta E_n = \frac{e^2(n+1)^2}{2C_g} - \frac{e^2 n^2}{2C_g} - eV_g \tag{D.4}$$

Note that without $C_t \ll C_g$ approximation, the answer is $\Delta E_n = \frac{e^2}{C_g+2\,C_t}\left(n+\frac{1}{2}\right) - eV_g C_g/(2\,C_t + C_g)$ (not required to receive full marks).

D.2 $\mathcal{N}$ is a minimal integer n for which $\Delta E_n \geq 0$. Consider the marginal case of $\Delta E_{\mathcal{N}} = 0$ which is achieved at some $V_g = V_0$,

$$\Delta E_{\mathcal{N}}(V_0) = 0 = \frac{e^2}{C_g}\left(\mathcal{N} + \frac{1}{2}\right) - eV_0 \tag{D.5}$$

If V_g would go slightly larger than V_0, then ΔE_n would go negative and then minimal n that makes a positive ΔE_n would jump from $\mathcal{N}$ to $\mathcal{N}+1$. Hence $E_c = \Delta E_{\mathcal{N}+1}(V_0)$. This gives

$$\Delta E_{\mathcal{N}+1}(V_0) = E_c = \frac{e^2}{C_g}\left(\mathcal{N} + 1 + \frac{1}{2}\right) - eV_0 = \boxed{\frac{e^2}{C_g}} \tag{D.6}$$

D.3 In a metal, only electrons in an energy range $\pm \approx k_B T$ around the Fermi level take part in the thermal motion. (Here k_{B} is the Boltzmann constant.) Typical energy of these electrons is $k_{\mathrm{B}}T$ per particle and it may not exceed characteristic single-electron addition energy E_c, $\boxed{k_{\mathrm{B}}T < E_c}$.

D.4 i. $\boxed{\tau = R_t\, C_t}$

ii. Quantum uncertainty of energy (life-time broadening) h/τ must be less than the energy difference between the states with n and $n+1$ electrons,

$$h/\tau < E_c \Rightarrow \frac{h}{R_t C_t} < \frac{e^2}{C_g} \tag{D.7}$$

$$\boxed{R_t > \frac{h}{e^2}\frac{C_g}{C_t}} > \frac{h}{e^2} \tag{D.8}$$

E. RF REFLECTOMETRY TO READ OUT SET STATE

E.1

$$\Gamma = \frac{Z_{\mathrm{SET}} - Z_0}{Z_{\mathrm{SET}} + Z_0} \tag{E.1}$$

$$\Gamma_{\mathrm{ON}} = \frac{10^5 - 50}{10^5 + 50} \approx 1 - 2\frac{50}{10^5} \tag{E.2}$$

$$\Gamma_{\mathrm{OFF}} = \lim_{Z_1 \to \infty} \frac{Z_1 - Z_0}{Z_1 + Z_0} = 1 \tag{E.3}$$

$$\Delta\Gamma = |\Gamma_{\mathrm{ON}} - \Gamma_{\mathrm{OFF}}| \boxed{\approx 1.0 \cdot 10^{-3}} \tag{E.4}$$

E.2 Large change in reflectance requires the impedance Z_1 of the circuit to switch between $Z_1 < Z_0$ to $Z_1 > Z_0$ as the SET between ON ($Z_{\rm SET} = 100{\rm k}\Omega$) and OFF ($Z_{\rm SET} = \infty$).

In the OFF state of the SET, the circuit is an disspationless LC contour with resonance frequency $\omega_0 = 1/\sqrt{L_0 C_0}$ and its impedance is 0. If we choose

$$\boxed{L_0 = \frac{1}{\omega_{\rm rf}^2 C_0}} \tag{E.5}$$

then the imedance of the $\omega_0 = \omega_{\rm rf}$.

Since $Z_{\rm tot}$ (the total impedance of the circuit) in the OFF state of the SET equals to 0, the reflectance i $\Gamma_{\rm OFF} = -1$. As we switch to the ON state with $Z_{\rm SET} = R_{\rm SET} = 10^5\Omega$, the change in reflectance will be large if $|Z_{\rm tot}|$ in this ON state is on the order of Z_0 or larger, which is indeed the case.

For the ON state and $\omega_0 = \omega_{\rm rf}$

$$Z_{\rm tot} = \left(\frac{1}{\frac{1}{j\,\omega\,C_0}} + \frac{1}{R_{\rm SET}}\right)^{-1} + j\,\omega L_0 = \frac{R_{\rm SET}}{1 + j\,\omega C_0\,R_{\rm SET}} + j\,\omega\,L_0 = \frac{R_{\rm SET} + j\,\sqrt{L_0/C_0}}{1 + R_{\rm SET}^2 C_0/L_0} \tag{E.6}$$

For $C_0 = 0.4\cdot 10^{-12}\,{\rm F}$, $Z_0 = 50\,\Omega$ and $\omega_{\rm rf} = 2\pi\cdot 10^8\,{\rm Hz}$, we have $\boxed{L_0 = 6.33\,\mu{\rm H}}$, $Z_{\rm tot} = (158 + 6.3\,j)\Omega$, $\Gamma_{\rm ON} = 0.5198 + 0.0145\,j$, and $\boxed{\Delta\Gamma = 1.52}$.

F. CHARGE SENSING WITH A SINGLE LEAD QUANTUM DOT

F.1 The SLQD readout circuit contains only reactive elements, so $|\Gamma| = 1$ will always be one. The OFF state of the SLQD corresponds to an inductor L_0 and a capacitor C_0 connected in parallel. We again choose

$$\boxed{\omega_{\rm rf} = 1/\sqrt{L_0 C_0}} \tag{F.1}$$

so that $Z_{\rm tot}$ is the OFF state is infinite and $\Gamma_{\rm OFF} = 1$.

The ON state corresponds to $Z_{\rm SET} = -j\frac{1}{\omega_{\rm rf} C_q}$ and $Z_{\rm tot}$ at $\omega_{\rm rf} = \omega_0$ is just the impedance of the SLQD

$$Z_{\rm tot} = \frac{1}{(j\omega_{\rm rf}L_0)^{-1} + j\omega_{\rm rf}(C_0 + C_q)} = -j\frac{1}{\omega_0 C_q} = -j\frac{C_0}{C_q}Z_C \tag{F.2}$$

For the complex phase of $\Gamma_{\rm ON} = (Z_{\rm tot} - Z_0)/(Z_{\rm tot} + Z_0)$ to be significantly different from zero, we need $|Z_{\rm tot}| \sim Z_0$ since $Z_{\rm tot}$ is purely imaginary. Hence

$$\boxed{Z_C \sim \frac{C_q}{C_0}Z_0} \tag{F.3}$$

F.2 If L_0 is fixed, we can still operate the circuit at the frequency

$$\boxed{\omega_{\rm rf} = 1/\sqrt{L_0 C_0}} \tag{F.4}$$

that gives $\Gamma_{\rm OFF} = 1$. However, we need to deduce a way to increase $|Z_{\rm tot}|$ even if $Z_C \ll C_q Z_0/C_0$ is not sufficient. One of the ways to do that is to add an additional capacitance C_m is series with rest of the circuit. This will give (at $\omega_{\rm rf} = \omega_0$)

$$Z_{\rm tot} = -j\left(\frac{C_0}{C_q}Z_C + \frac{1}{\omega_0 C_m}\right) = -j\omega_0^{-1}\left(C_q^{-1} + C_m^{-1}\right) \tag{F.5}$$

We can satisfy the condition $|Z_{\rm tot}| = Z_0$ (and hence $\Gamma_{\rm ON} = j$ and $\Delta\Gamma = \sqrt{2} \sim 1$) with

$$C_m = \frac{C_q}{Z_0 C_q \omega_{\rm rf} - 1} = \frac{C_q\sqrt{L_0 C_0}}{Z_0 C_q - \sqrt{L_0 C_0}} \tag{F.6}$$

$$\boxed{C_m = \frac{C_q Z_C}{Z_0 C_q/C_0 - Z_C}} \overset{Z_C \ll Z_0 C_q/C_0}{\approx} \frac{1}{Z_0\,\omega_{\rm rf}} \tag{F.7}$$

Theory
Question 2: X-ray jets from active galactic nuclei
Solutions

Asian Physics Olympiad Adelaide 2019

Part A: 1d fluid model of a jet

A1

If you consider a prism of plasma in the jet frame, it contains a number of particles N, has length l in the direction of motion, and cross sectional area A. The total number of particles in the volume is invariant on transformation into the AGN frame, however the volume occupied by the plasma changes as lengths are contracted in the direction of motion, while perpendicular lengths are unchanged. Hence, $A' = A$, and $l' = l/\gamma$.

This gives us two relationships:

$$N = n(s)Al \tag{1}$$

and

$$N = n'(s)Al/\gamma \tag{2}$$

Equating these gives

$$n(s)Al = n'(s)Al/\gamma \quad ,$$

which leads to

$$n'(s) = \gamma n(s) \quad . \tag{3}$$

A2

The particles in the jet have a bulk flow speed of $v(s)$, so in a time Δt a volume $V = A(s)v(s)\Delta t$ crosses the cross section of the jet. Using the number density in the AGN frame,

$$\begin{aligned} F_\mathrm{p}(s) &= n'(s)A(s)v(s) && (4)\\ &= \gamma(s)n(s)A(s)v(s) && (5) \end{aligned}$$

A3

As the plasma travels along the jet there are no particles passing through the side boundary of the jet. Hence, the total flux through the curved edges of the jet is zero, and the total flux into the jet is the flux in through the cross section at s_1 is $F_\mathrm{p}(s_1)$ and the total flux out of the jet is $F_\mathrm{p}(s_2)$. There is an additional term in the continuity equation due to the mass injection. There are $\alpha V/\mu_\mathrm{pp}$ particles injected.

This gives

$$\gamma(s_2)v(s_2)n(s_2)A(s_2) - \gamma(s_1)v(s_1)n(s_1)A(s_1) = \alpha V/\mu_\mathrm{pp} \tag{6}$$

A4

Similarly, in the AGN frame the energy flux

$$F_\mathrm{E}(s) = n'(s)A'(s)v(s)\epsilon'_\mathrm{av}(s) \quad . \tag{7}$$

We use previous results for all quantities except average energy per particle.

Consider the total energy in a volume ΔV of the plasma, $E_\mathrm{tot} = \epsilon_\mathrm{av}N$ in the jet frame. As this is the proper frame v(s)=0.

Transforming to the AGN frame, $E'_\mathrm{tot} = \gamma(s)\epsilon_\mathrm{av}N$, and $\epsilon'_\mathrm{av} = \gamma\epsilon_\mathrm{av}$.

Hence,

$$F_\mathrm{E}(s) = (\gamma(s))^2\, n(s)A's)v(s)\epsilon_\mathrm{av}(s) \quad . \tag{8}$$

Energy conservation requires that the total energy flux out of the jet is equal to the energy added through injection of mass, so

$$(\gamma(s_2))^2\, v(s_2)n(s_2)A(s_2)\epsilon_\mathrm{av}(s_2) - (\gamma(s_1))^2\, v(s_1)n(s_1)A(s_1)\epsilon_\mathrm{av}(s_1) = \alpha V c^2 \tag{9}$$

A5

From the defintion of jet power and also (8),

$$P_j(s) = (\gamma(s))^2\, n(s)A's)v(s)\epsilon_{\mathrm{av}}(s) - \dot{M}c^2 \quad . \tag{10}$$

Here $\dot{M}$ is the flux of mass flux across the surface, so $\dot{M} = F_{\mathrm{p}}(s)\mu_{\mathrm{pp}}$ and

$$P_j(s) = (\gamma(s))^2\, n(s)A's)v(s)\epsilon_{\mathrm{av}}(s) - F_{\mathrm{p}}(s)\mu_{\mathrm{pp}}c^2 \quad . \tag{11}$$

In order to find how jet power varies along the jet, we consider jet power at two points along the jet.

$$P_{\mathrm{j}}(s_2) - P_{\mathrm{j}}(s_1) = (\gamma(s_2))^2\, n(s_2)A'(s_2)v(s_2)\epsilon_{\mathrm{av}}(s_2) - F_{\mathrm{p}}(s_2)\mu_{\mathrm{pp}}c^2 \tag{12}$$

$$- \left((\gamma(s_2))^2\, n(s_1)A'(s_1)v(s_1)\epsilon_{\mathrm{av}}(s_1) - F_{\mathrm{p}}(s_1)\mu_{\mathrm{pp}}c^2\right) \quad . \tag{13}$$

We can identify the two terms with ϵ_{av} to be those from the left hand side of (8), and the two terms with μ_{pp} are $\mu_{\mathrm{pp}}c^2$ times the left hand side of (6). Making these substitutions,

$$P_{\mathrm{j}}(s_2) - P_{\mathrm{j}}(s_1) = \alpha V c^2 - \alpha V c^2 = 0 \quad . \tag{14}$$

This argument applies to arbitary s_1 and s_2, so the jet power is constant along the jet and $\frac{dP_{\mathrm{j}}}{ds} = 0$.

A6

We start from (10) and substitute $\epsilon_{\mathrm{av}} = \mu_{\mathrm{pp}}c^2 + \frac{13}{4}\frac{P}{n}$, to arrive at

$$P_{\mathrm{j}}(s) = (\gamma(s))^2\, n(s)A(s)v(s)(\mu_{\mathrm{pp}}c^2 + \frac{13}{4}\frac{P}{n(s)}) - \gamma(s)n(s)A(s)v(s)\mu_{\mathrm{pp}}c^2 \tag{15}$$

$$= (\gamma(s) - 1)\gamma(s)n(s)A(s)v(s)\mu_{\mathrm{pp}}c^2 + (\gamma(s))^2\, A(s)v(s)\frac{13}{4}P \tag{16}$$

$$= (\gamma(s) - 1)\dot{M}c^2 + (\gamma(s))^2\, A(s)v(s)\frac{13}{4}P \tag{17}$$

Rearranging to find $\dot{M}$ gives

$$\dot{M} = \frac{P_{\mathrm{j}} - \gamma(s)^2 A(s)v(s)\frac{13}{4}P}{(\gamma(s) - 1)c^2} \tag{18}$$

Using the relationship $P(s) = 5.7 \times 10^{-12}\left(\frac{s}{s_0}\right)^{-1.5}$ and substituting values for s_1 and s_2 respectively into (18), give $\dot{M}_1 = 2.8 \times 10^{19}\ \mathrm{kg\,s^{-1}}$ and $\dot{M}_2 = 5.2 \times 10^{19}\ \mathrm{kg\,s^{-1}}$.

Note: some of the input values are given to one significant figure only. Hence, answers which are correct to this degree of precision and are given to one or two significant figures are accepted as correct.

A7

From lorentz transforming ϵ_{av} from the jet frame where $v = 0$ to the AGN frame, the average momentum per particle is $p_{\mathrm{av}} = \gamma(s)\frac{v(s)}{c^2}\epsilon_{\mathrm{av}}$. As the momentum is directly proportional to the total energy, the flux argument is the same, and

$$\Pi(s) = \frac{F_{\mathrm{E}}}{c}\frac{v(s)}{c} \quad . \tag{19}$$

This can be related to the jet power and $\dot{M}$,

$$\Pi(s) = \left(\frac{P_{\mathrm{j}}}{c} + \dot{M}c\right)\frac{v(s)}{c} \quad . \tag{20}$$

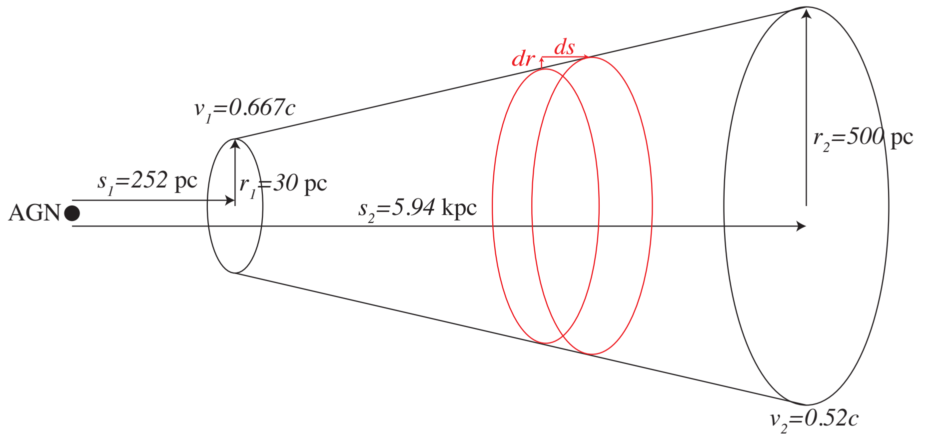
Again, there is no particle flux, and hence no momentum flux through the sides of the jet, so the total momentum flux out of the jet is

$$\Pi = \Pi(s_2) - \Pi(s_1) \quad . \tag{21}$$

Substituting values for the jet at s_2 and s_1 gives $\Pi = 1.9 \times 10^{27}\ \mathrm{kg\,m\,s^{-2}}$.

A8

The total force on the jet due to external pressure has contributions from the cross section at s_1, $F_1 = P(s_1)A(s_1)$, at s_s, $F_2 = P(s_2)A(s_2)$, and from the pressure on the curved surface. We have a linear relationship $s(r) = s_1 + \frac{s_2 - s_1}{r_2 - r_1}(r - r_1)$.



The nett pressure force on the surface is only the component in the s direction. As the force is perpendicular to the surface, this results in a factor of $\frac{dr}{ds}$. Consequently

$$dF = 2\pi r P(s) dr \quad , \tag{22}$$

where $P(s) = 5.7 \times 10^{-12} \left(\frac{s}{s_0}\right)^{-1.5}$.

The total force due to the external pressure,

$$F_{\mathrm{Pr}} = F_1 - F_2 + \int_{r_1}^{r_2} dF \quad . \tag{23}$$

Evaluating the integral gives $\int_{r_1}^{r_2} dF = 9.8 \times 10^{26}$ N, so $F_{\mathrm{Pr}} = 8.2 \times 10^{26}$ N.

A9

As there are no other forces on the jet, it is expected that $\Pi = F_{\mathrm{Pr}}$.

The % deviation is $|(\Pi - F_{\mathrm{Pr}})/F_{\mathrm{Pr}}| \approx 40\%$

Gas of ultrarelativistic electrons

B1

The total energy per volume is

$$\int_0^\infty \epsilon f(\epsilon) d\epsilon$$

B2

Consider the particles colliding with a surface ΔA,with the normal to the surface in the z-direction, in time Δt. As the electrons are ultrarelativistic, theirs speeds are all approximately c. We assume that the collisions with wall are elastic, and electrons depart with their parallel mometnum unchanged and $p_{z,\text{ final}} = -p_z$. Hence, $\Delta p_z = 2p_z$, where $p_z = \frac{\epsilon}{c}\cos\theta$, since the electrons are ultrarelativistic and $E \approx pc$.

The distribution is isotropic so electrons are equally likely to be travelling in any direction.

All electrons within a parallelepiped of length $c\Delta t$ which approach the surface at an angle θ will hit it in the time Δt. The volume of the paralleleiped is $c\Delta t \Delta A \cos\theta$. From here, the total change in momentum is

$$\begin{aligned}
\Delta p_z &= \int_0^\infty \int_0^{\pi/2} \int_0^{2\pi} 2f(\epsilon) p_z c\Delta t \Delta A \cos\theta \frac{\sin\theta}{4\pi} d\phi d\theta d\epsilon \qquad (24)\\
&= \frac{2\Delta t \Delta A}{4\pi} \int_0^{\pi/2} \sin\theta \cos^2\theta d\theta \int_0^{2\pi} d\phi \int_0^\infty \epsilon f(\epsilon) d\epsilon \qquad (25)\\
&= \frac{2\Delta t \Delta A}{4\pi} \times \frac{1}{3} \times 2\pi \int_0^\infty \epsilon f(\epsilon) d\epsilon \qquad (26)
\end{aligned}$$

B3

As the remaining integral in the expression above was identified as the energy per volume in B1, $\Delta p_z = \Delta t \Delta A \frac{1}{3}\frac{E}{V}$. The pressure is the force per area normal to the wall, so $P = \frac{\Delta p_z}{\Delta t}\frac{1}{\Delta A}$. Combining these gives $P = \frac{E}{3V}$, or $E = 3PV$, which is the equation of state.

B4

For an adiabatic process $dQ = 0$ so $dE = dW = -PdV$. $dE = d(3PV) = 3PdV + 3VdP$, so equating these expressions gives

$$3PdV + 3VdP = -pdV \tag{27}$$
$$4PdV = -3VdP \tag{28}$$
$$4\frac{dV}{V} = -3\frac{dP}{P} \tag{29}$$
$$4\int_{V_0}^{V}\frac{dV'}{V'} = -3\int_{P_0}^{P}\frac{dP'}{P} \tag{30}$$
$$4\ln\left(\frac{V}{V_0}\right) = -3\ln\left(\frac{P}{P_0}\right) \tag{31}$$
$$\frac{PV^{4/3}}{P_0V_0^{4/3}} = 1 \tag{32}$$

Synchrotron emission

C1

An electron in a magnetic field has a component of its velocity, $v\cos\phi$ along the magnetic field, and $v\sin\phi$ perpendicular to the field. The parallel component of the velocity remains constant, but in the perpendicular direction the electron experiences a force in a direction perpendicular to its motion, so it undergoes simple harmonic motion. The perpendicular component of its velocity is Ωr where Ω is its angular frequency and r the radius of the circular motion. The force on the electron is $\mathbf{F}_\mathrm{B} = q\mathbf{v}\times\mathbf{B} = e\Omega rB\sin\phi$. The acceleration of the electron is perpendicular to the direction of motion, so $F_B = \gamma ma$, where a is the acceleration and m the mass of the electron. For uniform circular motion, $a = -\Omega^2 r$, so

$$F_\mathrm{B} = \gamma m\Omega^2 r \tag{33}$$
$$e\Omega rB\sin\phi = \gamma m\Omega^2 r \tag{34}$$
$$\Omega = \frac{eB\sin\phi}{\gamma m} \tag{35}$$

C2

The observer only sees the synchrotron emission when they are within the forward light cone. As the electron is gyrating around the magnetic field, this direction is changing. The observer is in this light cone for time $\Delta t = \frac{2\theta}{\Omega} = \frac{2m}{eB}$. However, the emitting electron is moving directly toward the observer over this time, so although the light emitted at the start of the pulse is ahead of the light at the end of the pulse, it is only ahead by $c\Delta t\left(1-\frac{v}{c}\right)$. The pulse then has an apparent duration of

$$\Delta t_a = \Delta t\left(1-\frac{v}{c}\right) \quad .$$

Since $\left(1-\frac{v}{c}\right)\left(1+\frac{v}{c}\right) = 1-\frac{v^2}{c^2} = \frac{1}{\gamma^2}$, we can write $\left(1-\frac{v}{c}\right) = \frac{1}{\gamma^2\left(1+\frac{v}{c}\right)}$. As the electrons are ultrarelativistic, $\left(1+\frac{v}{c}\right) = 2$, and

$$\Delta t_\mathrm{a} = \frac{m_e}{\gamma^2 eB} \quad .$$

C3

$$\nu_\mathrm{chr} \approx \frac{1}{\Delta t_\mathrm{a}} = \frac{\gamma^2 eB}{m_e}$$

C4

Making a linear approximation,

$$\tau \approx -\frac{E}{\left(\frac{dE}{dt}\right)} \tag{36}$$

$$= \frac{6\pi\varepsilon_0 m^4 c^5}{e^4 B^2 \sin^2\phi}\frac{1}{E} \tag{37}$$

Synchrotron emission from an AGN jet

D1

As the magnetic field is frozen in, and magnetic flux is constant, the magnetic field must decrease as the area increases in the expansion.

For a small area A, $B_0 A_0 = BA$. Since $A \propto V^{2/3}$, $B = B_0(A_0/A) = B_0\left(\frac{V}{V_0}\right)^{-2/3}$

D2

A volume of plasma V_0 with number density n_0 contains a total number of particles $N = n_0 V_0$. As the volume expands, the total number remains constant, so $n = N/V = (V/V_0)n_0$.

The internal energy of the plasma $E = 3PV$, and since $PV^{4/3} = P_0 V_0^{4/3}$, $EV^{1/3} = E_0 V_0^{1/3}$. The scaling for particle energy with volume is then $E = (V/V_0)^{-1/3}E_0$. This means that the particles initially with energies between ϵ_0 and $\epsilon + d\epsilon$, will have energies between $(V/V_0)^{-1/3}\epsilon_0$ and $(V/V_0)^{-1/3}(\epsilon + d\epsilon)$. As $((V/V_0)^{-1/3}\epsilon)^{-p} = (V/V_0)^{-p/3}\epsilon^{-p}$.

Hence, we can write

$$f(\epsilon) = \kappa\epsilon^{-p} \quad .$$

The value of κ is determined by the relationship

$$\int_0^\infty \kappa\epsilon^{-p} d\epsilon = N/V \quad .$$

Given

$$\int_0^\infty \kappa_0\epsilon^{-p} d\epsilon = N/V_0$$

$\kappa_0 V_0 = \kappa V$, and

$$f(\epsilon) = \left(\frac{V}{V_0}\right)^{-1}\kappa_0\epsilon^{-p}$$

D3

As the energy loss rate due to synchrotron emission increases as E^2, and the cooling time decreases as $1/E$, the more energetic electrons lose energy more rapidly. If we consider electrons with energies $\epsilon_1 < \epsilon_2$, both will move to lower energies in the distribution, but $df/dt \propto E^2$, so $\frac{df}{dt}|_{\epsilon_2} > \frac{df}{dt}|_{\epsilon_1}$. This will reduce the relative number of electrons with higher energies, and steepen the power law of the electron energy distribution.

D4

For the knots in Centaurus A there is no change in the x-ray spectrum, so this rules out synchrotron cooling as in that case the spectrum would steepen (Part D3). Hence adiabatic cooling is more likely for these two knots.

For the knots in M87, there is no change in brightness in other bands. Adiabatic expansion would reduce the number density at all energies (Part D2) and hence brightness at all wavelengths, so this is not likely. Hence, synchrotron cooling is more likely for these two knots.

Reference sheet for markers

Note: some results below were used for the previous version of part **A.10**, and are no longer needed.

Coordinate systems for convenience (note: use of matrices not needed) xyz from XYZ

$$\begin{bmatrix} \hat{\mathbf{x}} \\ \hat{\mathbf{y}} \\ \hat{\mathbf{z}} \end{bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \hat{\mathbf{X}} \\ \hat{\mathbf{Y}} \\ \hat{\mathbf{Z}} \end{bmatrix}$$

123 from xyz

$$\begin{bmatrix} \hat{\mathbf{1}} \\ \hat{\mathbf{2}} \\ \hat{\mathbf{3}} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} \hat{\mathbf{x}} \\ \hat{\mathbf{y}} \\ \hat{\mathbf{z}} \end{bmatrix}$$

Position of point A from centre of mass, in xyz and 123 frames:

$$\begin{aligned} \mathbf{a} &= \alpha R\hat{\mathbf{3}} - R\hat{\mathbf{z}} \\ &= \alpha R\sin\theta\hat{\mathbf{x}} + R(\alpha\cos\theta - 1)\hat{\mathbf{z}} \\ &= R\sin\theta\hat{\mathbf{1}} + R(\alpha - \cos\theta)\hat{\mathbf{3}} \end{aligned} \tag{1}$$

Useful products:

$$\hat{\mathbf{z}} \times \hat{\mathbf{3}} = \sin\theta\hat{\mathbf{y}} \tag{2}$$

(3)

Note (given in question):

$$\left(\frac{\partial \mathbf{A}}{\partial t}\right)_{\mathbf{K}} = \left(\frac{\partial \mathbf{A}}{\partial t}\right)_{\widetilde{\mathbf{K}}} + \boldsymbol{\omega} \times \mathbf{A} \tag{4}$$

Time derivatives:

$$\dot{\hat{\mathbf{3}}} = \boldsymbol{\omega} \times \hat{\mathbf{3}} \tag{5}$$

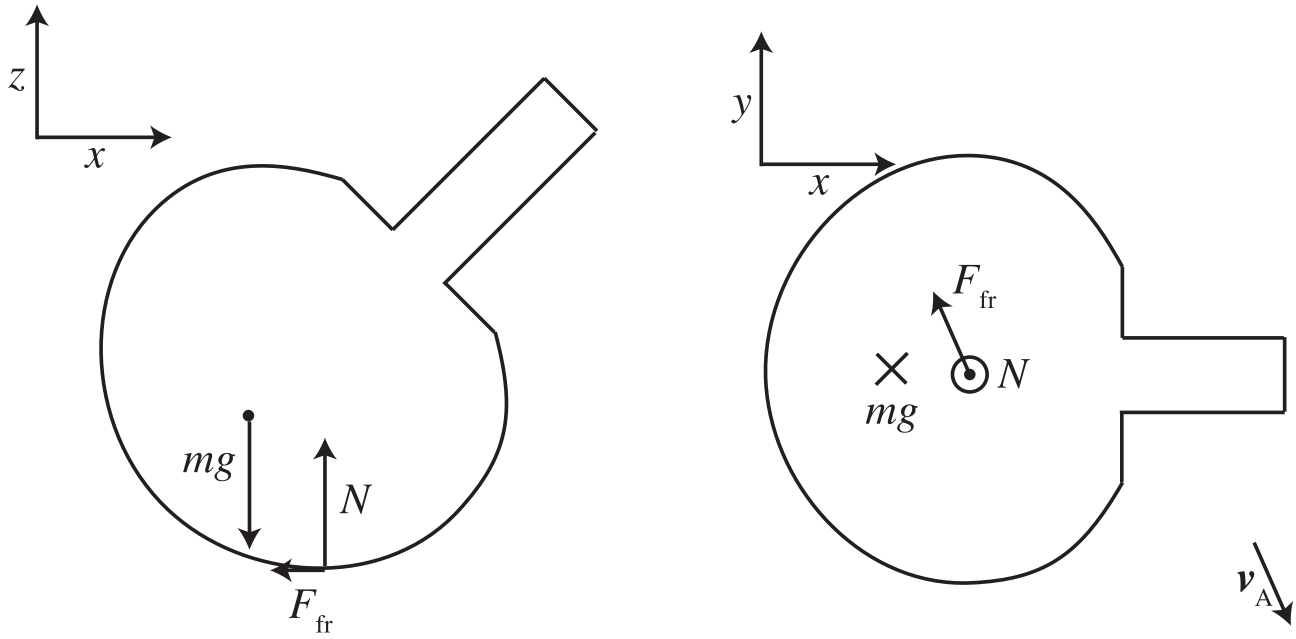
$$\dot{\hat{\mathbf{x}}} = \dot{\phi}\hat{\mathbf{y}} \tag{6}$$

$$\dot{\hat{\mathbf{y}}} = -\dot{\phi}\hat{\mathbf{x}} \tag{7}$$

Solutions: Tippe Top

1. (**1.0 marks**)

   Free body diagrams:



Note: the direction of $\mathbf{F}_f$ must be opposite to the direction of $\mathbf{v}_A$, but is otherwise unimportant. Sum of forces:

$$\begin{aligned}\mathbf{F}_{\text{ext}} &= (N - mg)\hat{z} + \mathbf{F}_f \quad \text{(sufficient for full marks)} \qquad (8)\\ &= (N - mg)\hat{z} - \frac{\mu_k N}{|v_A|}\mathbf{v_A}\end{aligned}$$

Sketched $\mathbf{v_A}$ must be in opposite direction to $\mathbf{F}_f$ on xy diagram.

2. (**0.8 marks**)

   Sum of torques:

$$\begin{aligned}\boldsymbol{\tau}_{\text{ext}} &= \mathbf{a} \times (N\hat{\mathbf{z}} + \mathbf{F}_f) \qquad (9)\\ &= (\alpha R\hat{\mathbf{3}} - R\hat{\mathbf{z}}) \times (N\hat{\mathbf{z}} + F_{f,x}\hat{\mathbf{x}} + F_{f,y}\hat{\mathbf{y}})\\ &= \alpha RN\hat{\mathbf{3}} \times \hat{\mathbf{z}} + \alpha R(\sin\theta\hat{\mathbf{x}} + \cos\theta\hat{\mathbf{z}}) \times (F_{f,x}\hat{\mathbf{x}} + F_{f,y}\hat{\mathbf{y}}) - R\hat{\mathbf{z}} \times (F_{f,x}\hat{\mathbf{x}} + F_{f,y}\hat{\mathbf{y}})\\ &= -\alpha RN\sin\theta\hat{\mathbf{y}} + \alpha R\sin\theta F_{f,y}\hat{\mathbf{z}} + \alpha R\cos\theta F_{f,x}\hat{\mathbf{y}} - \alpha R\cos\theta F_{f,y}\hat{\mathbf{x}} - RF_{f,x}\hat{\mathbf{y}} + RF_{f,x}\hat{\mathbf{x}}\\ &= RF_{f,y}(1 - \alpha\cos\theta)\hat{\mathbf{x}} + [RF_{f,x}(\alpha\cos\theta - 1) - \alpha RN\sin\theta]\,\hat{\mathbf{y}} + \alpha R\sin\theta F_{f,y}\hat{\mathbf{z}} \qquad (10)\end{aligned}$$

3. (**0.4 marks**)

   Motion at A satisfies

$$\mathbf{v_A} = \dot{\mathbf{s}} + \boldsymbol{\omega} \times \mathbf{a} \qquad (11)$$

where $\boldsymbol{\omega}$ is the total angular velocity of the top in the centre of mass frame (this is deteremined in the next part). Want to show that $\mathbf{v_A} \cdot \hat{\mathbf{z}} = 0$.

To show this, take time derivative of contact condition in XYZ or xyz frame (note: either is suitable, as we only need the $\hat{\mathbf{z}}$ component, and $\hat{\mathbf{z}} = \hat{\mathbf{Z}}$).

Contact condition:

$$\begin{aligned} (\mathbf{s}+\mathbf{a})\cdot\hat{\mathbf{z}} &= 0 \quad \text{at all times} \\ \Rightarrow \frac{d}{dt}(\mathbf{s}+\mathbf{a})\cdot\hat{\mathbf{z}} &= 0 \quad \text{at all times} \end{aligned} \tag{12}$$

Note we only care about the z-component, and $(\boldsymbol{\omega}\times\hat{\mathbf{z}})\cdot\hat{\mathbf{z}} = 0$. Then, using 11, 1, and 5,

$$\begin{aligned} \mathbf{v_A}\cdot\hat{\mathbf{z}} &= (\dot{\mathbf{s}} + \boldsymbol{\omega}\times\mathbf{a})\cdot\hat{\mathbf{z}} \\ &= \left(\dot{\mathbf{s}} + \alpha R\boldsymbol{\omega}\times\hat{\mathbf{3}}\right)\cdot\hat{\mathbf{z}} \\ &= \left(\dot{\mathbf{s}} + \alpha R\frac{d\hat{\mathbf{3}}}{dt}\right)\cdot\hat{\mathbf{z}} \\ &= (\dot{\mathbf{s}} + \dot{\mathbf{a}})\cdot\hat{\mathbf{z}} = 0 \end{aligned} \tag{13}$$

4. (**0.8 marks**)

Total angular velocity $\boldsymbol{\omega}$ of top is the sum of three distinct rotations:

$$\boldsymbol{\omega} = \dot{\theta}\hat{\mathbf{2}} + \dot{\phi}\hat{\mathbf{z}} + \dot{\psi}\hat{\mathbf{3}}$$

Use transformations shown in figure 3 or otherwise to transform into xyz or 123 frame:

$$\boldsymbol{\omega} = \dot{\psi}\sin\theta\hat{\mathbf{x}} + \dot{\theta}\hat{\mathbf{y}} + (\dot{\psi}\cos\theta + \dot{\phi})\hat{\mathbf{z}} \tag{14}$$

$$\boldsymbol{\omega} = -\dot{\phi}\sin\theta\hat{\mathbf{1}} + \dot{\theta}\hat{\mathbf{2}} + (\dot{\psi} + \dot{\phi}\cos\theta)\hat{\mathbf{3}} \tag{15}$$

5. (**1.0 marks**)

Where $\mathbf{I}$ is the inertia tensor

$$\begin{bmatrix} I_1 & 0 & 0 \\ 0 & I_1 & 0 \\ 0 & 0 & I_3, \end{bmatrix}$$

we have

$$\begin{aligned} E_T &= K_T + K_R + U_G \\ &= \frac{1}{2}\boldsymbol{\omega}\cdot\mathbf{I}\boldsymbol{\omega} + \frac{1}{2}m\dot{\mathbf{s}}^2 + mgR(1-\alpha\cos\theta) \end{aligned}$$

From 11,

$$\begin{aligned} \dot{\mathbf{s}} &= \mathbf{v_A} - \boldsymbol{\omega}\times\mathbf{a} \\ &= \mathbf{v_A} - (\dot{\theta}\hat{\mathbf{2}} + \dot{\phi}\hat{\mathbf{z}} + \dot{\psi}\hat{\mathbf{3}})\times(\alpha R\hat{\mathbf{3}} - R\hat{\mathbf{z}}) \\ &= v_x\hat{\mathbf{x}} + v_y\hat{\mathbf{y}} - \left(\dot{\theta}\alpha R\hat{\mathbf{1}} - \dot{\theta}R\hat{\mathbf{z}} + \dot{\phi}\alpha R\hat{\mathbf{z}}\times\hat{\mathbf{3}} - \dot{\psi}R\hat{\mathbf{3}}\times\hat{\mathbf{z}}\right) \\ &= \left(v_x + \dot{\theta}R(1-\alpha\cos\theta)\right)\hat{\mathbf{x}} + \left(v_y - R\sin\theta(\alpha\dot{\phi} + \dot{\psi})\right)\hat{\mathbf{y}} + \dot{\theta}\alpha R\sin\theta\hat{\mathbf{z}} \end{aligned}$$

using 2. Thus

$$\begin{aligned} E_T = &\frac{1}{2}\left[I_1(\dot{\phi}^2\sin^2\theta + \dot{\theta}^2) + I_3(\dot{\psi} + \dot{\phi}\cos\theta)^2\right] \\ &+ \frac{m}{2}\left[\left(v_x + \dot{\theta}R(1-\alpha\cos\theta)\right)^2 + \left(v_y - R\sin\theta(\alpha\dot{\phi} + \dot{\psi})\right)^2 + \dot{\theta}^2\alpha^2R^2\sin^2\theta\right] + mgR(1-\alpha\cos\theta) \end{aligned}$$

6. (**0.4 marks**)

From 10,

$$\frac{d\mathbf{L}}{dt} \cdot \hat{\mathbf{z}} = \sum \boldsymbol{\tau} \cdot \hat{\mathbf{z}} = \alpha R \sin\theta F_{f,y} \tag{16}$$

7. (**1.4 marks**)

Changes in energy: $h = \mathbf{s} \cdot \hat{\mathbf{z}}$ increases, so $\dot{U}_G > 0$.

At start and end (phases **I** and **V**) there is little translation so $K_T \sim 0$ at **I** and **V**. Thus, energy transfer is from K_R to U_G.

Normal force does no work. Frictional force does work at point A. Direction is $-\mathbf{v_A}$:

$$W = \int \mathbf{F}_f \cdot \mathbf{v_A} \; dt < 0$$
$$\Rightarrow \frac{d}{dt} E_T = -\mu_k N |\mathbf{v_A}|$$

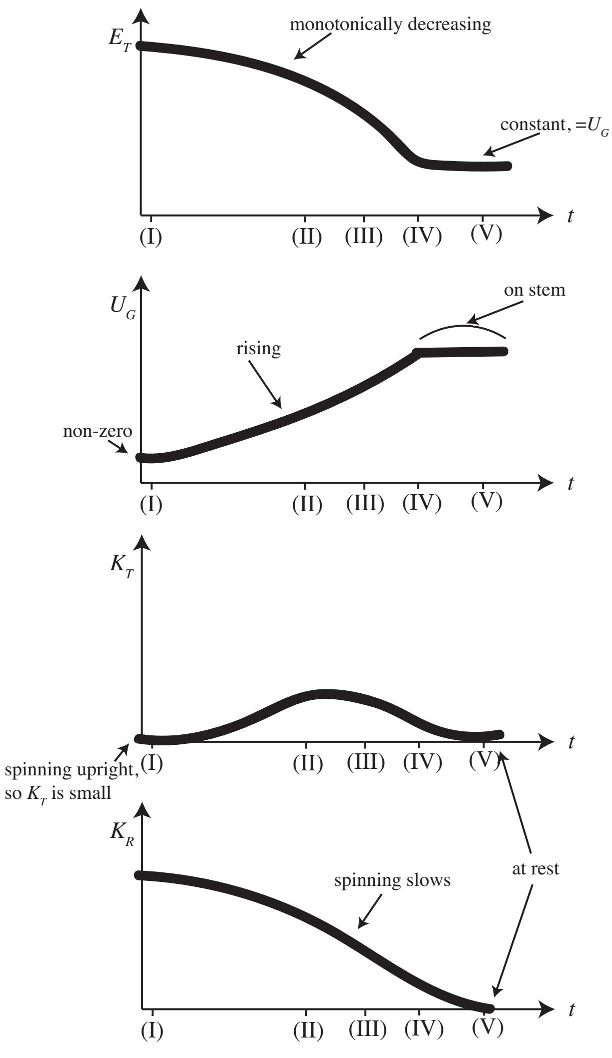
Thus $\mathbf{F}_f$ decreases the total energy monotonically.

16 implies only the $\mathbf{F}_f . \hat{\mathbf{y}}$ acts to decrease $\mathbf{L} \cdot \hat{\mathbf{z}}$. Energy transfer from K_R to U_G, caused by component of frictional force in $\hat{\mathbf{y}}$ direction, so component of resultant torque is in the $\mathbf{a} \times \hat{\mathbf{y}}$ direction.

8. (**2.0 marks**)

Expectation (see figure):

- E_T: monotonically decreasing
- K_R: monotonically decreasing; zero at V
- K_T: zero at I and V; higher between; close to zero at IV
- U_G: flat at start and finish; higher at end; increases from I to IV then flat; increase roughly at same time that K_{rot} decreases



9. (**0.5 marks**)

   From 15,

$$\mathbf{L} = \mathbf{I}\boldsymbol{\omega} = I_1\left(-\dot{\phi}\sin\theta\hat{\mathbf{1}} + \dot{\theta}\hat{\mathbf{2}}\right) + I_3(\dot{\psi} + \dot{\phi}\cos\theta)\hat{\mathbf{3}} \tag{17}$$

   Taking cross product with $\hat{\mathbf{3}}$:

$$\begin{aligned} \mathbf{L} \times \hat{\mathbf{3}} &= I_1\left(\dot{\phi}\sin\theta\hat{\mathbf{2}} + \dot{\theta}\hat{\mathbf{1}}\right) \\ &= I_1(\boldsymbol{\omega} \times \hat{\mathbf{3}}) \end{aligned} \tag{18}$$

10. (**1.7 marks**)

   About any axis through the centre of mass,

$$\frac{d\mathbf{L}}{dt} \neq 0 \Leftrightarrow \tau_{\text{ext}} \neq 0$$

   External torque given by 9,

$$\begin{aligned} \boldsymbol{\tau}_{\text{ext}} &= \mathbf{a} \times (N\hat{\mathbf{z}} + \mathbf{F}_f) \\ &\Rightarrow \tau_{\text{ext}} \cdot \mathbf{a} = 0 \\ &\frac{d\mathbf{L}}{dt} \cdot \mathbf{a} = 0 \end{aligned}$$

   Thus, angular momentum in the direction of $\mathbf{a}$ must be constant, so $\mathbf{v} = \mathbf{a}$.

   To demonstrate this mathematically, 5, 10, 18 allow

$$\begin{aligned} -\dot{\lambda} &= \frac{d\mathbf{L}}{dt} \cdot \mathbf{a} + \alpha R \mathbf{L} \cdot \frac{d\hat{3}}{dt} \\ &= (\mathbf{a} \times (N\hat{\mathbf{z}} + \mathbf{F_f})) \cdot \mathbf{a} + \frac{\alpha R}{I_1}\mathbf{L} \cdot (\boldsymbol{\omega} \times \mathbf{L}) \\ &= 0 \end{aligned}$$

Theory
Q1
RF reflectometry for spin readout for silicon quantum computing
Marking scheme. Version 1.1

Question part	Total marks	Partial marks	Explanation for partial marks and special cases
A.1	0.2	0.1 0.1	Velocity dimensionally correct and is less than c Correct final answer • 0.2 total for correct answer with no justification
A.2	0.2	0.1 0.1	Applying Gauss theorem Correct final answer
	0.3	0.1 0.1 0.1	Capacitance formula Electric potential formula Correct final answer
A.4	0.3	0.1 0.1 0.1	Bio-Savart law or equivalent for magnetic field of a wire Inductance formula Correct final answer
A.5-i	0.8	0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1	Adding one extra δL, δC link does not change the semi-infinite wire Equating impedance the circuit with one extra link to Z_0 Sum of impedance in parallel (L and Z_0) Sum of impedance in series Correct equation for Z_0 Relating δL, δC to L_x, C_x $\delta L \to 0$ limit simiplification Correct final answer
A.5-ii	0.2	0.1 0.1	Correct b/a formula Correct final answer
B.1	1	0.1 0.2 0.1 0.1 0.1 0.1 0.1 0.1 0.1	Z_0 in terms of L_x, C_x Method of images Magnetic flux and its relation to L_x Adding B-fields of the real and the imaginary wires Correct L_x Potential and its relation to C_x Adding E fields of two wires Capacitance per length C_x Final result for Z_0
C.1	1	0.1 0.1 0.1 0.1 0.2 0.1 0.1 0.1 0.1	Starting with a workable approach (would lead to answer if followed through) Concept of equating voltage amplitudes Correct voltage matching equation Current conservation concept Current conservation equation (-0.1 if signs are wrong) Apply Omh's law Correct equation to solve for V_r/V_i Solving the equation Final answer in term of Γ • Proof of work required. Max 0.2 for stating the answer with no proof
C.2	0.2	0.1 0.1	π-shift of reflected signal implies $\Gamma < 0$ Correct condition stated

D.1(i)	1		A variety of approaches acceptable if lead to correct answer
		0.1	Charge on QD equals $-ne$
		0.3	Treat charge on the QD as the charge on C_g(neglecting tunnel junctions)
		0.3	Voltage drop across capacitor computed correctly
		0.3	Equation for φ_n in terms of sum of voltages(-0.1 if signs are wrong)
			• -0.1 if the term with ½ is missing
D.1(ii)	0.5		A variety of approaches acceptable if lead to correct answer
		0.1	Relation between energy and potential
		0.3	Correct intermediate formula for ΔE_n
		0.1	Correct final answer
D.2	0.5	0.2	A difference of ΔE_n and ΔE_{n+1} considered
		0.1	Use the formula from D.1(ii) for ΔE_n.
		0.2	Correct final answer
D.3	0.5	0.2	$k_B T$identified the relevant thermal energy
		0.2	E_c identified as the relevant scale for electron energy
		0.1	Correct final answer
			• no penalty for numerical prefactors of order 1 or using $\ll$ instead of $<$
D.4	0.8	0.2	$\tau \sim R_t C_t$ tau on order of RC
		0.3	h/τ is identified as relevant scale for the fluctuation energy
		0.1	E_c identified as the relevant scale for electron energy
		0.2	Correct comparison sign and correct final answer
			• answer for τ without justification acceptable
			• no penalty for numerical prefactors of order 1 or using $\ll$ instead of $<$
E.1	0.2	0.1	At least one of Γ computed correctly
		0.1	Correct final answer
E.2	0.8	0.1	Understand $\Delta\Gamma \sim 1$ requires change in Z_{tot} on the order of Z_0
		0.1	Identifying OFF state as an LC circuit
		0.2	Choosing L_0 from the LC resonance condition
		0.1	Calculate Γ_{OFF}
		0.1	Correct Z_{tot} for ON state
		0.1	Correct numerical answer for L_0
		0.1	Correct numerical answer for Γ_{ON}
F.1	1	0.1	Calculate Z_{tot} for OFF state
		0.2	Choosing $\omega_{rf}$to match a resonance
		0.2	Calculate Z_{tot} for ON state
		0.3	Connect $\Delta\Gamma \sim 1$ with Z_{tot} values
		0.2	Correct calculation and final answer
F.2	0.5	0.1	Diagram with the added element is functional
		0.2	Capacitance in series with the rest of the circuit
		0.1	Demonstrate that the added element leads to $\Delta\Gamma \sim 1$
		0.1	Correct formula characterizing the added element

Theory
Question 2: X-ray jets from active galactic nuclei
Marking scheme

			Available	Score
A1	Length contraction	0.1		
	Answer	0.2	0.3	
A2	Answer	0.2	0.2	
A3	Curved edge flux zero	0.1		
	End contributions	0.2		
	Mass injection term	0.2	0.5	
A4	Transform from jet to AGN frame	0.2		
	Energy flux through cross section	0.1		
	Mass injection term	0.1		
	Final answer	0.2	0.6	
A5	Express P_j in terms of jet parameters	0.2		
	Comparing two points	0.1		
	Using previous relationships	0.2		
	Final answer	0.1	0.6	
A6	Expression for $\dot{M}$, in known variables	0.2		
	Values	0.2	0.4	
A7	Average momentum per particle - rel	0.2		
	Expression for total p flux	0.2		
	Numerical value	0.1	0.5	
A8	Pressure from 3 surfaces	0.1		
	Correctly constructed integral for curved surface force	0.2		
	Final answer	0.2	0.5	
A9	Relationship	0.1		
	% difference	0.1	0.2	
B1	Integral including correct limits	0.2	0.2	
B2	Factor of two in change of momentum	0.1		
	$E = pc$	0.1		
	Number of electrons hitting wall in Δt	0.2		
	Set up of integral	0.2		
	Final answer	0.2	0.8	
B3	Identify E/V	0.2		
	Identify pressure	0.2		
	Equation of state	0.2	0.6	
B4	$dQ = 0$ so $dE = dW$	0.2		
	dE from equation of state	0.1		
	Setting up integral	0.1		
	Final relationship	0.2	0.6	
C1	Force perpendicular to v, $F = \gamma ma$	0.3		
	Magnetic force	0.1		
	$a = v\Omega$	0.1		
	Gyrofrequency	0.2	0.7	

C2	Find time between emission of front and back of pulse	0.1		
	Find relationship to apparent time	0.2		
	Final answer with ultrarelativistic approximation	0.2	0.5	
C3	Frequency from characteristic timescale	0.2		
	Final expression	0.1	0.3	
C4	Linear approximation	0.1		
	Expression	0.1	0.2	
D1	Constant flux	0.1		
	Area scaling	0.1		
	Final expression	0.2	0.4	
D2	Scaling of number density	0.1		
	Scaling of energy	0.2		
	Applying scaling of energy implies p unchanged.	0.3		
	Integral for number density	0.2		
	Final expression	0.2	1	
D3	Ticking steeper (and nothing else)	0.1		
	Reasonable justification (e.g. cooling time is shorter for higher E)	0.2	0.3	
D4	Cen A: adiabatic expansion, D3, consistency			
	One or both of the correct boxes are ticked in the first two rows	0.1		
	One or both of the correct part numbers are stated in the first two rows	0.1		
	Both of the first two rows are completely correct (they should be identical).	0.1		
	M87: synchrotron/other, D2, consistency			
	One or both of the correct boxes are ticked in the second two rows	0.1		
	One or both of the correct part numbers are stated in the second two rows	0.1		
	Both of the second two rows are completely correct (they should be identical).	0.1	0.6	

Theory Q3 MARKING SCHEME: TIPPE TOP

Marks in brackets are partial marks, and do not count toward totals.

Negative marks in brackets are relative to full marks available for that portion, i.e. relative to unbracketed line above. (full) is equivalent to (−0.0).

ecf = 'error carried forward'

Question	Required answer	Total Marks	Given Marks
A.1 (1.0)	$\mathbf{F}_{\text{ext}} = (N - mg)\hat{z} + \mathbf{F}_f$ or equivalent ($\mathbf{F}_f$ expanded but restricted to $\hat{\mathbf{x}}$ or $\hat{\mathbf{y}}$ direction) free body diagrams with $\mathbf{F}_g$, $N\hat{\mathbf{z}}$, $\mathbf{F}_f$ in right directions (direction of $\mathbf{F}_f$ in xz-plane diagram does not matter ($\mathbf{F}_f$ drawn in $\hat{\mathbf{x}}$ or $\hat{\mathbf{y}}$ direction but $\mathbf{F}_f$ term correct in expression above) ($\mathbf{F}_f$ drawn in $\hat{\mathbf{x}}$ or $\hat{\mathbf{y}}$ direction and $\mathbf{F}_f$ term expanded but restricted to $\hat{\mathbf{x}}$ or $\hat{\mathbf{y}}$ direction) (only one correct diagram) $\mathbf{v_A}$ in $-\mathbf{F}_f$ direction (must be within XY plane)	0.2 (−0.1) 0.6 (full) (−0.1) (−0.2) 0.2	
A.2 (0.8)	$\boldsymbol{\tau}_{\text{ext}} = \mathbf{a} \times (N\hat{\mathbf{z}} + \mathbf{F}_f)$ (total force at point A wrong but consistent with A.1) (have $\boldsymbol{\tau}_{\text{ext}} = \mathbf{a} \times \mathbf{F}_A$ but force at A wrong) correct $\mathbf{a} = \alpha R\hat{\mathbf{3}} - R\hat{\mathbf{z}}$ getting to final answer $\sum \boldsymbol{\tau}_{\text{ext}} = RF_{f,y}(1 - \alpha\cos\theta)\hat{\mathbf{x}} + [RF_{f,x}(\alpha\cos\theta - 1) - \alpha RN\sin\theta]\,\hat{\mathbf{y}} + \alpha R\sin\theta F_{f,y}\hat{\mathbf{z}}$ (partial credit if started off right but cross/dot products wrong)	0.3 (ecf 0.3) (0.2) 0.2 0.3 (0.1-0.2)	
A.3 (0.4)	recognising $\mathbf{v_A} \cdot \hat{\mathbf{z}}$ is needed $\mathbf{v_A} = \dot{\mathbf{s}} + \boldsymbol{\omega} \times \mathbf{a}$ stated differentiating contact condition in xyz or XYZ frame	0.1 0.2 0.1	
A.4 (0.8)	$\boldsymbol{\omega} = \dot{\theta}\hat{\mathbf{2}} + \dot{\phi}\hat{\mathbf{z}} + \dot{\psi}\hat{\mathbf{3}}$ (implicitly recognising total angular velocity is sum of several angular terms) (each correct angular term) (above if not written explicitly, but answer is correct in either xyz or 123 frame) $\hat{2}, \hat{3}$ to xyz frame correct $\hat{\mathbf{z}}$ to 123 frame correct **Note:** credit for these transformations can be given in other parts (e.g. **A.5**) if not allocated here	0.4 (0.1) (0.1) (full) 0.2 0.2	
A.5 (1.0)	$E_T = K_T + K_R + U_G$ $U_G = mgR(1 - \alpha\cos\theta)$ $K_R = \frac{1}{2}(I_1(\dot{\phi}^2\sin^2\theta + \dot{\theta}^2) + I_3(\dot{\psi}) + \dot{\phi}\cos\theta)^2$ (dimensionally correct term in form of $\sum I\boldsymbol{\omega}^2$) $K_T = \frac{m}{2}\left[(v_y - R\sin\theta(\alpha\dot{\phi} + \dot{\psi}))^2 + \dot{\theta}^2\alpha^2R^2\sin^2\theta\right]$	0.3 0.1 0.3 (0.1) 0.3	
A.6 (0.4)	taking dot product for z-component	0.1	

	correct result from **A.2** **Note:** no credit given for $\frac{d\mathbf{L}}{dt} = \boldsymbol{\tau}_{\mathbf{ext}}$ here, but can allocate those marks for **A.10** for work here	0.3	
A.7 **(1.4)**	 U_G increases as centre of mass rises (above implied in figure in **A.8**) $K_T \sim 0$ at start and finish (above implied in figure in **A.8**) therefore energy transfer from K_R to U_G normal force does no work identify y-component of $\mathbf{F}_f$ (only stating friction force) correct value of $\frac{E_T}{dt}$ **Note:** This was 0.2 in previous version of marking scheme, which gave the wrong total	 0.2 (full) 0.2 (full) 0.2 0.1 0.4 (0.2) **0.3**	
A.8 **(2.0)**	 E_T monotonically decreasing E_T constant from **IV** to **V** U_G rising from **I** to **IV** U_G constant from **IV** to **V** $K_T \sim 0$ at **I** $K_T = 0$ at **V** K_T increases then decreases between **I** and **V** K_R monotonically decreasing $K_R = 0$ at **V** K_R decreasing while U_G is rising **Note:** scale of U_G including at start does not matter. Labels in solutions not required. (a)–(e) in solutions changed to **I**–**V** on answer sheet.	 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2	
A.9 **(0.5)**	 $\mathbf{L} = \mathbf{I}\boldsymbol{\omega}$ where $\mathbf{I}$ is clearly the inertia tensor correct $\mathbf{L} \times \hat{3}$ in 123 frame (above done with $\mathbf{L}$ and $\boldsymbol{\omega}$ in 123 frame, without full expansion of L_1, L_2 terms) $k = I_1$ (can be implied)	 0.1 0.2 (full) 0.2	
A.10 **(1.7)**	 $\frac{d\mathbf{L}}{dt} = \boldsymbol{\tau}_{\text{ext}}$ $\therefore \frac{d\mathbf{L}}{dt} \cdot \mathbf{v} = \boldsymbol{\tau}_{\text{ext}} \cdot \mathbf{v}$ for any vector $\mathbf{v}$ $\boldsymbol{\tau}_{\text{ext}} \perp \mathbf{a}$ or other valid argument $\therefore \frac{d\mathbf{L}}{dt} \cdot \mathbf{a} = 0$ $\mathbf{v} = \mathbf{a}$ or any scalar multiple of $\mathbf{a}$ demonstrating $\dot{\lambda} = 0$	 0.3 0.2 0.3 0.2 0.3 0.4	

General instructions: Experimental Examination (20 points)

May 9, 2019

The experimental examination lasts for 5 hours and is worth a total of 20 points.

Before the exam

- You must not open the envelopes containing the problems before the sound signal indicating the beginning of the competition.
- The beginning and end of the examination will be indicated by a sound signal. There will be announcements every hour indicating the elapsed time, as well as fifteen minutes before the end of the examination (before the final sound signal).

During the exam

- Dedicated answer sheets are provided for writing your answers. Write your answers into the appropriate tables, boxes or graphs on the corresponding answer sheet (marked A). For every problem, there are extra blank working sheets for carrying out detailed work (marked W). Be sure to always use the working sheets that belong to the problem you are currently working on (check the problem number in the header). If you have written something on any sheet which you do not want to be graded, cross it out. Only use the front side of every page.
- In your answers, try to be as concise as possible: use equations, logical operators and sketches to illustrate your thoughts whenever possible. Avoid the use of long sentences.
- Estimates of uncertainties are **required** for all measurements unless explicitly stated otherwise in the question. You should also decide on the appropriate number of data points or measurement repetitions unless specific instructions are given. Please give an appropriate number of significant figures when stating numbers.
- Often, you may be able to solve later parts of a problem without having solved the previous ones.
- A list of physical constants is given on the next page.
- You are not allowed to leave your working place without permission. If you need any assistance, please draw the attention of a team guide by raising one of your flags ("I need water" if you need water, "toilet break" if you need to go to the toilet, "Extra paper, please!" if you need extra working sheets, "equipment/materials" if you have a problem with your equipment or materials or "I need help" in all other cases).

At the end of the exam

- At the end of the examination you must stop writing immediately.
- For every problem, sort the corresponding sheets in the following order: cover sheet (C), questions (Q), answer sheets (A), working sheets (W) and then extra sheets (Z) if you have them.
- Put all the sheets belonging to one problem into the envelope for that question. Also put the general instructions (G) into the remaining separate envelope. Also hand in empty sheets. You are not allowed to take any sheets of paper out of the examination area.
- Leave your writing equipment on the table.
- Wait at your table in silence until your envelopes are collected. Once all envelopes are collected your guide will escort you out of the examination area.

General Data Sheet

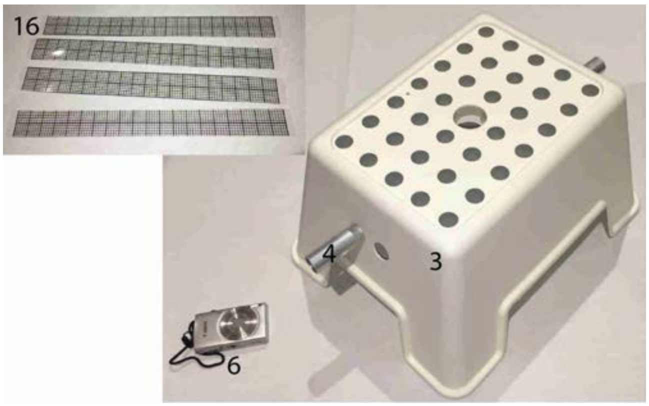
Speed of light in vacuum	c	$=$	$299\ 792\ 458\ \mathrm{m \cdot s^{-1}}$
Vacuum permeability	μ_0	$=$	$4\pi \times 10^{-7}\ \mathrm{kg \cdot m \cdot A^{-2} \cdot s^{-2}}$
Vacuum permittivity	ε_0	$=$	$8.854\ 187\ 817 \ldots \times 10^{-12}\ \mathrm{A^2 \cdot s^4 \cdot kg^{-1} \cdot m^{-3}}$
Elementary charge	e	$=$	$1.602\ 176\ 620\ 8(98) \times 10^{-19}\ \mathrm{A \cdot s}$
Mass of the electron	m_e	$=$	$9.109\ 383\ 56(11) \times 10^{-31}\ \mathrm{kg}$
Mass of the proton	m_p	$=$	$1.672\ 621\ 898(21) \times 10^{-27}\ \mathrm{kg}$
Mass of the neutron	m_n	$=$	$1.674\ 927\ 471(21) \times 10^{-27}\ \mathrm{kg}$
Atomic mass constant	m_u	$=$	$1.660\ 539\ 040(20) \times 10^{-27}\ \mathrm{kg}$
Rydberg constant	R_∞	$=$	$10\ 973\ 731.568\ 508(65)\ \mathrm{m^{-1}}$
Universal constant of gravitation	G	$=$	$6.674\ 08(31) \times 10^{-11}\ \mathrm{m^3 \cdot kg^{-1} \cdot s^{-2}}$
Acceleration due to gravity in Adelaide	g	$=$	$9.797\ \mathrm{m \cdot s^{-2}}$
Planck's constant	h	$=$	$6.626\ 070\ 040\ (81) \times 10^{-34}\ \mathrm{kg \cdot m^2 \cdot s^{-1}}$
Avogadro number	N_A	$=$	$6.022\ 140\ 857\ (74) \times 10^{23}\ \mathrm{mol^{-1}}$
Molar gas constant	R	$=$	$8.314\ 4598(48)\ \mathrm{kg \cdot m^2 \cdot s^{-2} \cdot mol^{-1} \cdot K^{-1}}$
Molar mass constant	M_u	$=$	$1 \times 10^{-3}\ \mathrm{kg \cdot mol^{-1}}$
Boltzmann constant	k_B	$=$	$1.380\ 648\ 52(79) \times 10^{-23}\ \mathrm{kg \cdot m^2 \cdot s^{-2} \cdot K^{-1}}$
Stefan-Boltzmann constant	σ	$=$	$5.670\ 367\ (13) \times 10^{-8}\ \mathrm{kg \cdot s^{-3} \cdot K^{-4}}$

Static response of a magnetically active fluid (10 points)

Introduction

Ferrofluids are suspensions of nanoparticles of magnetite (Fe_3O_4) in a carrier medium. They exhibit a range of interesting properties, and in particular a strong response to an applied magnetic field - they are sometimes described as superparamagnets. In this experiment you will be investigating empirically some of the properties of a ferrofluid using both static and dynamic testing methods, and using a range of experimental measurement and estimation techniques. The experiment is set up in two broad halves but it is suggested to work through the problems in order.

Equipment List



1. Small glass bottle with ferrofluid under a clear medium. **You are NOT permitted to open the bottle for any reason!**
2. Glass dish with sealed lid containing ferrofluid. **You are NOT permitted to open the lid of the dish for any reason!**
3. A combination light shroud and stand
4. Tube with adjustable magnet carrier (initially inserted through the stand)
5. Adjustable wooden base with nylon bolts for level adjustment
6. Camera with inserted memory card
7. 2 × N52 magnet, 14.2 mm × 3.2 mm
8. 1 × N42 magnet, 20.0 mm × 5.0 mm (not shown in figure)
9. 500 mm threaded rod for use as a lamp pole
10. Washer and wing nut for attaching pole to stand
11. Battery-powered lamp with threaded mounting hole
12. Aluminium foil for making light guides and blockers
13. Blutack for attaching various components as needed
14. Green wedge
15. Transparent 30 cm ruler
16. 4 × transparent grid strips
17. 2 × wooden spacers
18. Paper tape measure

Safety and Other Important Notes

In this experiment you will be using high strength magnets. If you allow the magnets to attract each other they may pinch your fingers, or collide and shatter. Be careful to control the magnets at all times and not leave them near to each other unattended. **Broken magnets will not be replaced.**

This experiment has two sealed chambers of fluid. You may not open either the small glass bottle or the glass dish with sealed lid at any time during the experiment. **If the sides of the dish become coated with ferrofluid, they will be very hard to see through so be careful not to tip the dish unnecessarily.**

Your lamp is battery operated. If you deem it necessary, you may ask for **one** additional set of batteries for your lamp when you need them during the experiment.

If you hold a magnet close against the ferrofluid for more than around ten seconds, it will cause the fluid to behave differently due to residual magnetisation and interactions with the surrounding fluid. Although your experiment can still be performed, it may be more difficult to see the right effects.

When you store your magnets, ensure that they are far enough apart so that they won't snap together. They must be placed at least as far apart as is shown in the diagram above.

Part A: Static Testing (1.6 points)

In this part of the experiment, you will be investigating the ferrofluid properties through measurements of its static response to a magnetic field.

Magnetic interaction: force on a ferrofluid

The small glass bottle contains a volume of ferrofluid surrounded by an unknown fluid with which the ferrofluid is immiscible. The ferrofluid has density 1.21×10^3 kg m^{-3}, and magnetic susceptibility $\chi = 2.64$.

The ferrofluid responds to the presence of a magnetic field **B** and has an induced dipole moment per volume of magnitude $m = \frac{\chi B}{\mu_0}$.

The field on the axis of a cylindrical magnet is approximately

$$B_z = \frac{B_r}{2}\left(\frac{z+l}{\sqrt{(z+l)^2+a^2}} - \frac{z}{\sqrt{z^2+a^2}}\right) \quad , \tag{1}$$

where z is the distance from the surface of the magnet, l is its thickness, a its radius and B_r the remanent field strength which is a property of the magnetic material from which the magnet is made. For the large magnet (made of N42) $B_r = 1.3$ T and for the small magnets (made of N52) $B_r = 1.4$ T.

The force per volume in the z direction (along the direction of the magnet's magnetisation) on the ferrofluid can be taken to be

$$\frac{f}{V} = \frac{\chi B_z \frac{dB_z}{dz}}{2\mu_0} \quad . \tag{2}$$

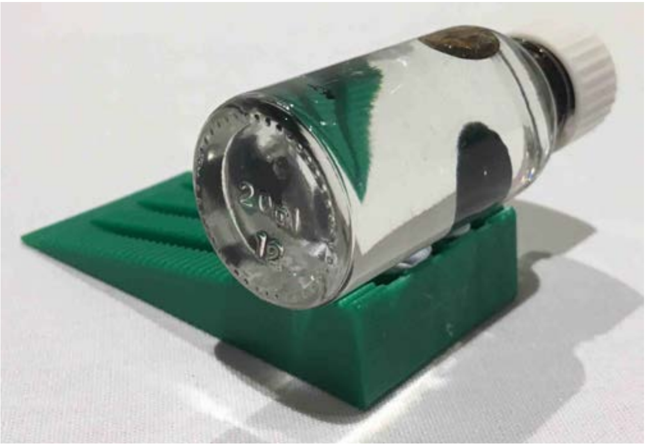
As this is tedious to calculate with the full field, you may use a dipolar approximation for the force on the ferrofluid in this part. Using this approximation the force per volume in the z direction is

$$\frac{f}{V} = -\frac{3\chi B_r^2 a^4 l^2}{8\mu_0 z^7} \tag{3}$$

Set up the stand so that the threaded rod through the aluminium tube has its flat face pointing downwards. You can rotate the aluminium tube to achieve this - make sure that the threaded rod does not hit the surface as you rotate the tube.

Stick the small bottle sideways to the top of the thick edge of the wedge using some of the blutack.

Magnet carrier in position for part A



Bottle setup for part A

A.1	Find the position of the large magnet where the ferrofluid is just able to be suspended in the clear unknown fluid and record the distance z on the answer sheet, along with its uncertainty. It can be difficult to achieve perfect balance, so if you are unable to keep the ferrofluid stably suspended, make the best estimate of the distance and its uncertainty. In the box on the answer sheet, draw a diagram showing how you measure the distance. Note that sometimes the ferrofluid may seem to 'split' into the magnetic blob and a separate, floating blob. This is usually due to the presence of a small amount of air in the bottle. You can use the magnet to adjust the position of the ferrofluid blob to find a clear space in the bottle to lift it.	0.8pt

A.2	Using your distance result and any other measurements as necessary, calculate the difference between the density of the ferrofluid and of the clear surrounding fluid, including its uncertainty.	0.8pt

Part B: Magnetic interaction: surface tension of a ferrofluid (1.2 points)

The ferrofluid moves under the influence of three energies: gravitational potential energy, surface energy associated with the surface tension, and the magnetic energy.

Using one of the magnets, observe what happens when you bring the magnet very close to the bottle. The spikes appear in the ferrofluid due to the normal field instability, which occurs when the effective frequency of gravity-capillary-magnetic waves in the fluid becomes imaginary.

The dispersion relation is

$$\omega^2 = \frac{gk\Delta\rho}{\rho_1 + \rho_2} + \frac{\sigma k^3}{\rho_1 + \rho_2} - \frac{k^2 \mu_0 M_0^2}{1 + (1+\chi)^{-1}}, \tag{4}$$

where σ is the surface tension of the ferrofluid at a ferrofluid-clear fluid interface, ρ_1 is the density of the ferrofluid, ρ_2 is the density of the clear fluid, $\Delta\rho = \rho_1 - \rho_2$, M_0 is the magnetisation in the ferrofluid, and k is the wavenumber.

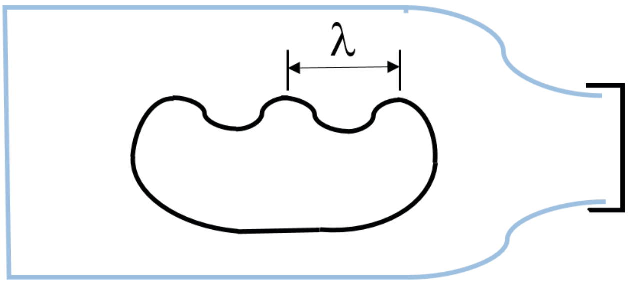
Applying the conditions $\omega^2 = 0$ and $\frac{\partial \omega^2}{\partial k} = 0$, the surface tension can be found in terms of the density difference and the effective wavelength of the perturbations to the fluid surface **at the point where the instability starts**. The relationship is

$$\sigma = \frac{g\Delta\rho\lambda^2}{4\pi^2}, \tag{5}$$

where λ is the distance between the centres of nearest neighbouring spikes when the magnetisation strength is at the instability threshold.

The magnet and carrier in position for part B.

Change the orientation of the threaded rod (rotating the tube while adjusting the rod position is the easiest way) so that you can raise and lower the magnet just under and through the hole in the top of the stand.



B.1	Using the glass bottle, take a measurement of the distance z_{crit} when the instability just starts to occur (peaks just start to form). Using the graticule or otherwise, measure the spacing of the peaks in the ferrofluid λ. at this position and record it. Estimate your uncertainties in both measurements. **Important hints:** if you hold the fluid strongly to the glass wall with a magnet, it will stick slightly to the glass, making your measurements more difficult. If this happens, you can use a magnet to draw the fluid away from the sticky area, and use another part of the bottle for this measurement.	0.6pt

B.2	Hence find the surface tension of the ferrofluid under the clear fluid, and its uncertainty.	0.6pt

Part C: Optical surface characterisation: non-spiking regime (4.1 points)

When the magnetic field is applied below the critical field, the surface of the fluid deforms to a first approximation as a balance between the magnetic and gravitational potential. In this next part we take the magnet to be sufficiently far from the fluid that it is well approximated by a dipolar field.

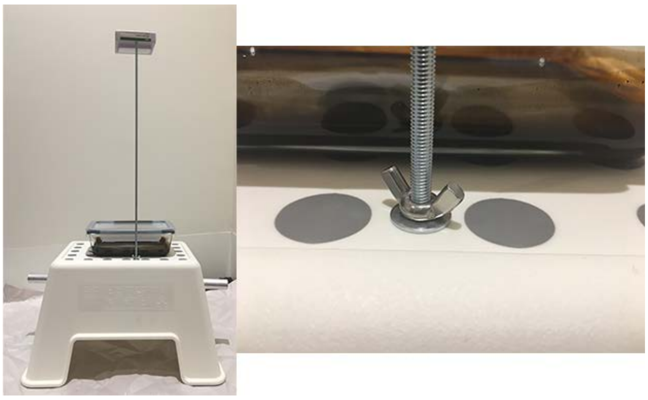
The surface deformation can be probed optically, using the surface of the fluid as an approximate spherical mirror. The effective radius of curvature of the centre of the deformation follows a power law, $R = \alpha z^n$ where α is a constant dependent on the materials and z is the distance of the magnet from the unperturbed surface of the fluid.

First we need to calibrate the magnetic threaded rod.

C.1	Use your equipment to find as precisely as you can the change in z for one turn of the threaded rod magnet carrier, including an uncertainty estimate. Record the measurements you use and draw a diagram of your setup.	0.6pt

Now take the glass dish of ferrofluid and place it on the stand, so that the hole in the centre of the stand is under the middle of the dish. *Do NOT open the sealed lid on the dish at any time during the experiment*. Load one of the small magnets onto the rod.

Thread the lamp onto the rod, and use the washer and wing nut to fix the threaded rod to the hole in the stand (see figure).



C.2	Using the relationship between the radius of curvature R and image magnification M for a spherical mirror, $R = \frac{2lM}{1-M}$ where l is the distance to the object, take measurements and then plot an appropriate graph to determine the constant n in the relationship above. Estimate the uncertainty in your answer.	3.5pt

Part D: Spiked surface characterisation: spike formation and disappearance (3.1 points)

For larger fields the surface will undergo the instability and form spikes as observed with the glass bottle.

D.1 Using a stack of one small and one large magnet, and the instability theory giving $\sigma = \frac{g\rho\lambda^2}{4\pi^2}$, determine the surface tension of the ferrofluid at an air interface. 0.5pt

D.2 Start with the magnet sufficiently far from the surface that no spikes are evident. Bring the magnet closer to the fluid and take distance readings for the appearance of each spike as it forms. Take another set of data as you withdraw the magnet, recording the position of the disappearance of each spike. Estimate the uncertainties in your measurements. 1.0pt

D.3 Plot a graph of the number of visible spikes against magnet distance z. Fit curves to your graph indicating clearly which direction the magnet was moving. 1.0pt

D.4 As the magnet's distance from the fluid surface changes, the fluid's gravitational, magnetic and surface energies change. Qualitatively sketch, as a function of the distance of the magnet from the fluid surface, the energy stored in surface energy and in magnetic potential energy. Mark any critical points from your previous graph and make clear the overall trend. You don't need to use the entire range of your data, just enough to show the idea. 0.6pt

Static response of a magnetically active fluid (10 points)

Part A: Static Testing (1.6 points)

Magnetic interaction: force on a ferrofluid

A.1 (0.8 pt)
Diagram:

$z =$

A.2 (0.8 pt)

Density difference $\Delta\rho =$

Part B: Magnetic interaction: surface tension of a ferrofluid (1.2 points)

B.1 (0.6 pt)
$z_{\text{crit}} =$

$\lambda =$

B.2 (0.6 pt)
$\sigma =$

Part C: Optical surface characterisation: non-spiking regime (4.1 points)

Optical surface characterisation: non-spiking regime

C.1 (0.6 pt)
Diagram

Measurements:

$\Delta z =$

C.2 $(3.5\ \mathrm{pt})$
Measurements:

C.2 (cont.)
Graph:

C.2 (cont.)

Relationship plotted on graph:

Space to work

$n =$

Part D: Spiked surface characterisation: spike formation and disappearance (3.1 points)

Spiked surface characterisation: spike formation and disappearance

D.1 (0.5 pt)

Surface tension of ferrofluid in air: $\sigma_{\text{fa}} =$

D.2 (1.0 pt)

Number of spikes	Magnet distance z	Δz

D.3 (1 pt)

D.4 (0.6 pt)
Sketch:

Additional graph paper

Additional graph paper

Wave pulses in a magnetically active fluid (10 points)

Introduction

In this question you will investigate the properties of wave pulses in ferrofluids. The surface wave pulses which can be generated in the fluids are due to the interaction of the effects of gravity, surface tension and magnetic forces.

For wave pulses, there is no single wavelength or frequency of the pulse, however, it is known that the speed of propagation of a pulse in the absence of a magnetic field is

$$v(d) = \kappa\sqrt{d}, \tag{1}$$

where d is the depth of the fluid and α is a constant of proportionality. This relationship only applies for smaller wave amplitudes. When the wave amplitude is large the changed fluid depth due to the pulse causes changes in speed of propagation resulting in nonlinear effects. When the nonlinear effects are not significant, wave pulses approximately maintain their profiles as they propagate. However, when nonlinear effects are significant the pulses can change their profile as they propagate and often develop ripples either ahead or behind of the main pulse.

Part A: Plane pulses (1.3 points)

(a) (b) (c)

Photos of the required set up, (a) the glass dish with ferrofluid on the wooden base, (b) the glass dish on the wooden base, under the light shroud and stand, and (c) the camera on the light shroud and stand.

In order to generate plane waves in your ferrofluid, place the container with the ferrofluid on the wooden base, with a long side of the dish along the barrier at the edge of the base. The barrier is to ensure that your dish moves only in one direction when pushed. Ensure that the base is flat and level. To generate pulses, push the dish sharply with your hand a distance of around 2 cm. To ensure consistency in your pulse generation, you can use blu-tack and/or wooden spacers on the wooden base to mark starting and finishing positions for the ferrofluid container. It is recommended that you practice generating pulses at least a few times to be able to generate more consistent pulses.

The stand should then be set up over the dish. The lamp must be used to provide adequate lighting to be able to observe pulses in the fluid. Ensure that you can generate plane wave pulses and observe them by eye through the stand. Once you are able to do this, place the camera on the stand and make a video of a pulse. Note that the lighting and pulse amplitude may need to be adjusted to make a useful video. To adjust the lighting you can use blu-tack to place the light in an appropriate position, and may wish to use the aluminium foil to block or further direct the light.

When adjusting the lighting it is important to consider how to minimise light directly from the source into the camera, and also how to minimise reflections from the lid of the container. Reminder: you must NOT remove the lid from the container for safety reasons. Two options which can be useful in different situations are to have very diffuse light from all directions within the stand, or to direct light onto the fluid through the glass sides of the container.

See the description of the camera in Appendix A for how to make and playback videos. Note that the default automatic settings of the camera are suitable for making the required videos. If you are having difficulty clearly recording the observed effects, you need to adjust the lighting to be able to more clearly observe the wave pulses.

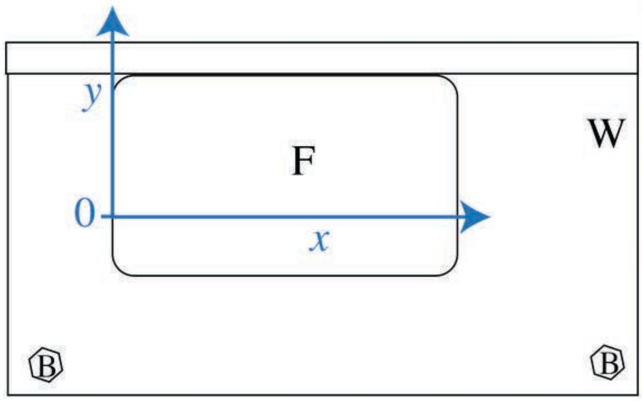
A.1	Draw a diagram of your set up, showing in particular how you positioned and directed the light.	0.3pt

A.2	Perform measurements and calculations from a video to find the speed of the waves in the ferrofluid. When performing measurements, also sketch diagrams of key frames of videos, showing important features, and marking any measurements made.	0.8pt

A.3	Make an estimate of the uncertainty of your measurement, showing any formulae you use to make the estimate.	0.2pt

Part B: Waves pulses in fluid of varying depth (3.4 points)

Insert the nylon bolts into the holes in the corner of the wooden base. By adjusting the bolts you can set up the platform so that the fluid depth in the container varies linearly with the distance from the lower edge (y-direction), and does not vary in the perpendicular direction (x-direction). We chose $y = 0$ to be where the depth of the fluid $d = 0$, so that the xy plane is the plane of the fluid's surface.



The set up of the glass dish with ferrofluid F on wooden base W so that the depth varies in the y-direction.

As the speed of waves in a fluid varies with depth, if a plane pulse is generated at one end of the container it will become curved as it propagates.

Set up your glass dish with ferrofluid on the wooden base so that you will best be able to characterise the variation of pulse speed with depth in the ferrofluid.

B.1	i. Draw a diagram of the container with ferrofluid as you set it up. Mark measurements, with uncertainties, of all distances which are important for you to know depth as a function of y in the container. ii. Write an expression for $d(y)$.	0.3pt

B.2	Generate plane wave pulses in your container, and qualitatively sketch a pulse you observe. Mark on your sketch the region where the pulse travels fastest with the letter A, and where it travels slowest with the letter B. Note: You will need to adjust the position of the light to clearly observe the pulses. To adjust the lighting you can use blu-tack to place the light in an appropriate position, and may wish to use the aluminium foil to make light blockers or light reflectors to further direct the light.	0.3pt

To a first approximation, we consider the pulse which is initially travelling in the x direction to remain travelling in the x direction only. Note: (x, y) are coordinates of points at time t are coordinates of points on the pulse at time t.

B.3	i. For a planar pulse which is at $x = 0$ when $t = 0$, find a relationship between x, y and t. ii. Mark on your diagram from B2, with the letter V, where within the glass dish with ferrofluid as you have it set up, this approximation is more valid?	0.3pt

B.4	Draw a diagram of your set up, showing in particular the position and direction of the light. Collect data to find κ and record in the table in the answer sheet. Include estimates of uncertainty for all data. When performing measurements, also sketch diagrams of key frames of videos, showing important features, and marking any measurements made.	1.2pt

B.5	i. Use a graphical method to calculate a value for κ. Include error bars for each measurement. Provide details of any formulae you use to calculate v, its estimated uncertainty Δv, d and its estimated uncertainty Δd. Record any additional calculated values for your graphs in the tables for B4. ii. From your data, state conditions on x, y and t for the relationship you developed in B3 to describe the observed wave pulses.	1.3pt

Part C: Wave and magnetic effects (1.8 points)

Warning: if the magnets collide they are likely to break. Broken magnets are dangerous, and yours will not be replaced if you break it.

As you observed in Question 1, in the presence of a magnetic field, the ferrofluid moves into the region of the strongest field. Your aim in this part is to investigate the interaction of wave a magnetic effects qualitatively.

Set up the ferrofluid container so that the ferrofluid has constant depth, as when you generated plane pulses. Next, place two small magnets underneath, as shown below. The magnets should have their poles aligned so that they repel each other when they are pushed together sideways in the channel on the wooden board. They should be positioned so that, with the ferrofluid in place, they are as close together as possible without repelling.

A safe way to put the magnets in place is to put **one** in the channel, then place the glass dish with ferrofluid over the track.You can use a wooden spacer in the track to position your magnet. The second magnet can then be slid into position, starting next to the dish, and using the spacer to push it along the channel under the ferrofluid.

Generate wave pulses using the following three methods:

- magnetically by rapidly withdrawing the large N42 magnet from near to the ferrofluid,
- mechanically by sliding the container on the wooden base, and
- mechanically by sliding the wooden base with the container fixed in place on top.

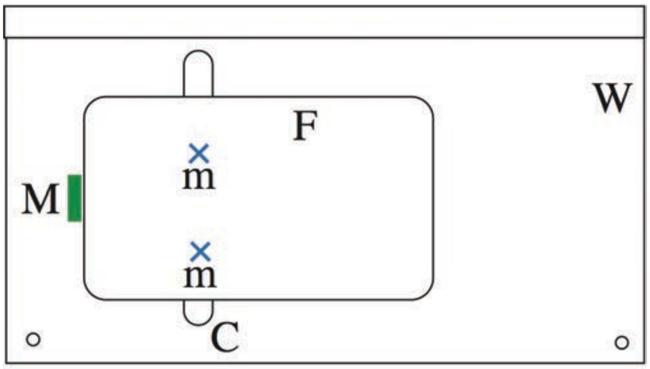


Diagram showing where to place the large magnet M, before rapidly removing it to generate a pulse travelling through the ferrofluid, where F is the glass dish with ferrofluid, m are the small magnets, W is the wooden base and C is the channel.

C.1	Sketch qualitative observations of the wave pulses for all three types of driving. Ensure that the diagrams clearly show how the presence of the magnets under the ferrofluid affects the wave front of the pulses. Identify all types of wave phenomena you observe. Mark with the corresponding number which effects cause which features of the observed pulse propagation. 1. reflection 2. refraction 3. doppler effect 4. beats 5. diffraction 6. interference (a) standing waves (b) from two slits or sources (c) from a diffraction grating (d) other	1.8pt

Part D: Internal properties of ferrofluid within a strong magnetic field (3.5 points)

In this part your aim is to quantify the effect of a magnet on pulse propagation in a ferrofluid.

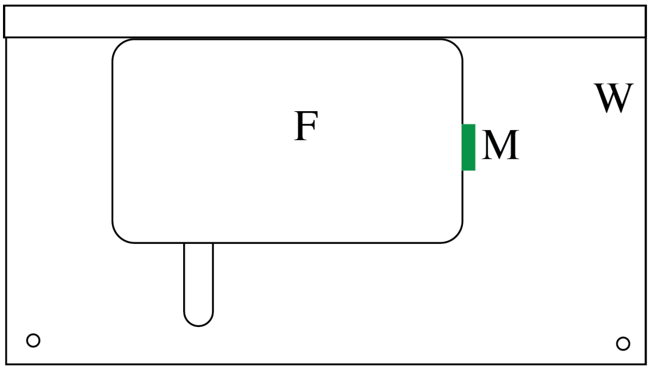


Diagram showing positioning of magnet in order to drive wave pulses in D1.

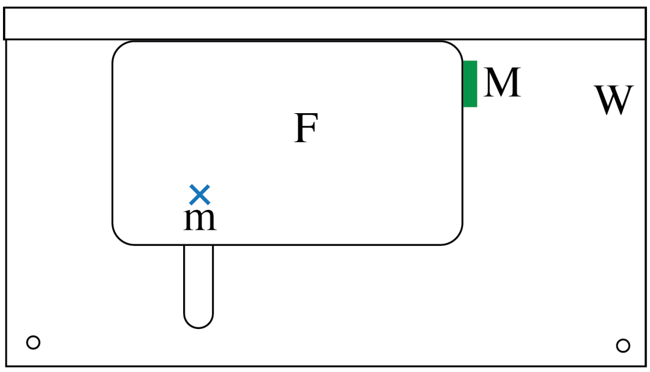
Set up the ferrofluid container so that the ferrofluid has constant depth, as when you generated plane pulses.

Generate pulses magnetically using the **large** N42 magnet, as in C1, and adjust the lighting to clearly observe the magnetically driven pulses.

D.1	Qualitative sketch a magnetically driven pulse in the ferrofluid.	0.2pt

D.2	Determine the speed of the pulse with its uncertainty. Sketch and diagram of your set up, including light position and direction, and record all data and formulae you use. When performing measurements, also sketch diagrams of key frames of videos, showing important features, and marking any measurements made.	0.8pt

Now place a single small magnet into the channel in the wooden base, and then place the dish and ferrofluid over the magnet. Its position can be adjusted using the wooden spacers, both in the track and to push the magnet around under the glass dish.



The position of the small magnet under the glass dish with ferrofluid is marked with an x, and the position of the large magnet, which is held outside the dish and then rapidly removed to generate a wave pulse, is labelled M.

Generate wave pulses magnetically, by starting with the large magnet in the position marked in the diagram above, and observe them travelling through the ferrofluid, including the region with the strong magnetic field.

D.3	Sketch qualitative observations of the wave pulses. Ensure that the diagrams clearly show how the presence of the magnet under the fluid affects the wave front.	0.4pt

D.4	Draw a diagram of your set up to determine the effect of the presence of the magnet under the fluid on the propagation time for a wave pulse. Clearly mark the positions of the magnets and also the light.	0.3pt

D.5	Make and record measurements with uncertainty estimates to determine the travel time of a pulse across the region with the magnet. When performing measurements, also sketch diagrams of key frames of videos, showing important features, and marking any measurements made.	1.0pt

D.6	Does the additional depth of the ferrofluid over the magnet explain the difference in speed of the wave pulses? Show calculations to support your answer.	0.8pt

Appendix A: How to use Canon IXUS-185

To turn the camera on or off press the button (O) labeled "ON/OFF" at the top of the camera. Note that the camera automatically turns off after a time.

To focus the camera, press the button (S) on the top of the camera part way.

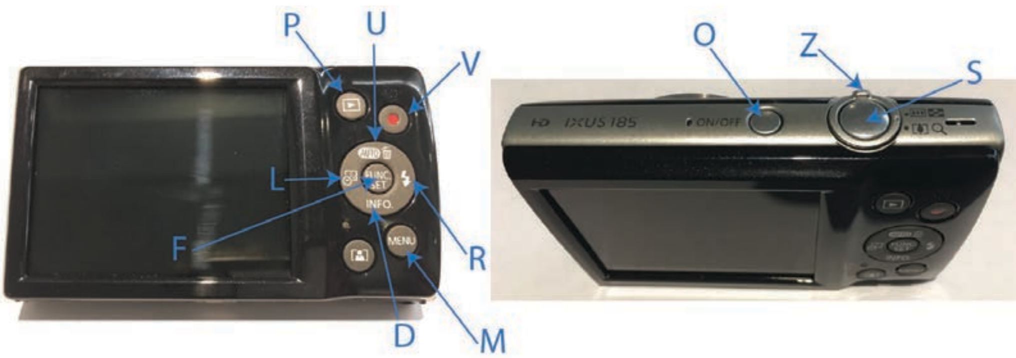
To take a photo press the button (S) on the top of the camera.

To take a video press the button marked with a red dot (V) to start recording. Press it again to stop recording. Note that the default HD videos record at 25 frames per second.

To view photos or videos you have taken, press the review button (P). Use the right (R) and left (L) buttons on the ring button on the back of the camera to navigate through your photos and videos.

- You can zoom in or out of photos using the ring (Z) on the top of the camera. Note: you cannot zoom after taking a video.
- To play a video press the "FUNC. SET" button (F) in the middle of the ring button on the back of the camera twice.
- To pause a video, press the "FUNC. SET" button (F) in the middle of the ring button on the back of the camera while the video is playing.
- When a video is paused you have options on the bottom of the screen. From left to right the options are: Exit, Play, Slow Motion, Skip Backwards, Previous Frame, Next Frame, Skip Forward. Use the right (R) and left (L) buttons on the ring button on the back of the camera to navigate through options, and the "FUNC. SET" button (F) in the middle of the ring button on the back of the camera to change the volume of video playback.

To zoom in or out, push the ring (Z) to the left to zoom out and to the right to zoom in.



To enter the camera settings menu press the button (M) labeled "MENU", then use the right ring button (R) on the back of the camera to enter the camera settings menu. Note that the first option is to mute the camera sounds.

- Use the right (R), left (L), up (U) and down (D) buttons on the ring button on the back of the camera to navigate through the menu.
- Use the "FUNC. SET" button (F) in the middle of the ring button on the back of the camera to select options.
- Use the "MENU" button (M) to exit the menu or to move back up through the menus.

To change the language of the camera, first enter the camera settings menu (see above). Press the down right button (D), labelled "INFO." on the back of the camera to scroll down the many page list to find "Language". Next press the right ring button (R) on the back of the camera to enter the list of language options. The the right (R), left (L), up (U) and down (D) buttons on the ring button on the back of the camera to navigate to the language of your choice. Use the "FUNC. SET" button (F) in the middle of the ring button on the back of the camera to select the language.

Note: You are not expected to change any settings on the camera, except for optionally changing the language, as the default automatic settings are suitable for the videos are you are required to make. You will benefit more from adjusting the lighting of your set up.

Wave pulses in a magnetically active fluid (10 points)

Part A: Plane pulses (1.3 points)

A.1 (0.3 pt)
Diagram of setup:

A.2 (0.8 pt)

A.2 (cont.)

A.3 (0.2 pt)

Part B: Waves pulses in fluid of varying depth (3.4 points)

Waves pulses in fluid of varying depth

B.1 (0.3 pt)
Diagram:

$d(y) =$

B.2 (0.3 pt)

B.3 (0.3 pt)
(i)

(ii)

B.4 (1.2 pt)

B.4 (cont.)

B.4 (cont.)

B.5 (1.3 pt)

$\kappa =$

$\Delta\kappa =$

B.5 (cont.)

Part C: Wave and magnetic effects (1.8 points)

C.1 (1.8 pt)

mechanically by sliding the container on the wooden base

mechanically by sliding the wooden base with the container fixed in place on top

pulses magnetically by rapidly withdrawing a magnet from near to the ferrofluid

Part D: Internal properties of ferrofluid within a strong magnetic field (3.5 points)

D.1 (0.2 pt)

D.2 (0.8 pt)

D.2 (cont.)

D.3 (0.4 pt)

D.4 (0.3 pt)

D.5 (1 pt)

D.6 (0.8 pt)

Additional graph paper

Asian Physics Olympiad Adelaide 2019

Experiment 1: Static response of a magnetically active fluid
Sample Solutions

General Note: these solutions look brief for many parts. Students do, however, have to manipulate the equipment and try to take good data, which will require taking some time. The solutions try to indicate some of the tricks.
Note that quantitative values will depend on the amount of fluid used and the containers – these should be tested and recalibrated when the experiment is used.

A1: Measurement taken on sample bottle: $\Delta z = 0.061 \pm 0.004$ m, when well balanced. (0.5 for good z, 0.3 for reasonable uncertainty) *Expect to see multiple attempts for full credit*

A2: Density difference gives the nett buoyant force, so balancing gravitational and magnetic forces: $\Delta\rho g = 3\,\chi B_r^2 a^4 l^2 / 8\mu_0 z^7$ (0.3)

Need to divide by g to rho, then substituting in the values for the large magnet yields

$\Delta\rho = 15$ kg m^{-3} (0.3)

Uncertainty sources: primarily z - hard to measure but can be controlled, and χ - not actually constant for a superparamagnet.
Any reasonable uncertainty method is fine. Using the data above, an estimate of 6 kg m^{-3} (0.2) could be made. Students should have some indication of where their labels come from.

Fresh bottles will be measured.

B1: $z_{crit} = 22 \pm 1$ mm (from uncertainty in when spikes appear) (0.2 + 0.1)

$\lambda = 6 \pm 1$ mm (from angle through the glass causing uncertainty about measurements of the incipient wavelength) (0.2 + 0.1)

Expect multiple attempts for full credit

Points will be given to good values. Doing this part is easiest if the bottle is on its side, although it can be done with the bottle upright.

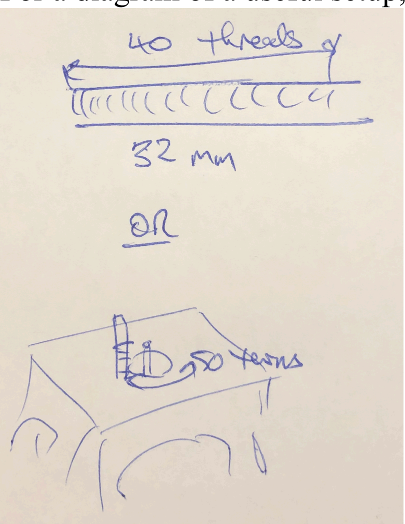
Note for future use: Values should be retaken using the actual experimental setup. They are sensitive to the bottles and magnets used.

B2: It may look as though there are a lot of points for nothing much here, but the credit is for the experimental skill that goes into taking high quality data. It is possible to be quite precise if one is careful and this will be rewarded here as well as the calculation details..

Surface tension may be calculated using the relationship above. It also requires the density difference from the earlier part, meaning that a large uncertainty in both parts will compound to the point where the uncertainty in this part is unreasonable.

For the values in these sample solutions $\sigma = 1.3 \times 10^{-2}$, N m^{-1} (0.3 if correct within an order of magnitude). Uncertainty estimate: in these data, $\Delta\sigma = 6 \times 10^{-3}$ N m^{-1} . (0.2 if correctly calculated from a reasonable method, 0.1 additional if less than 50%).

C1: There are many solution approaches.. All need to count threads and measure distance. For a diagram of a useful setup, **0.2**. For example:



0.2 for measurements and calculations.

Students should find that
$\Delta z = 0.80 \pm 0.02$ mm (**0.2**)

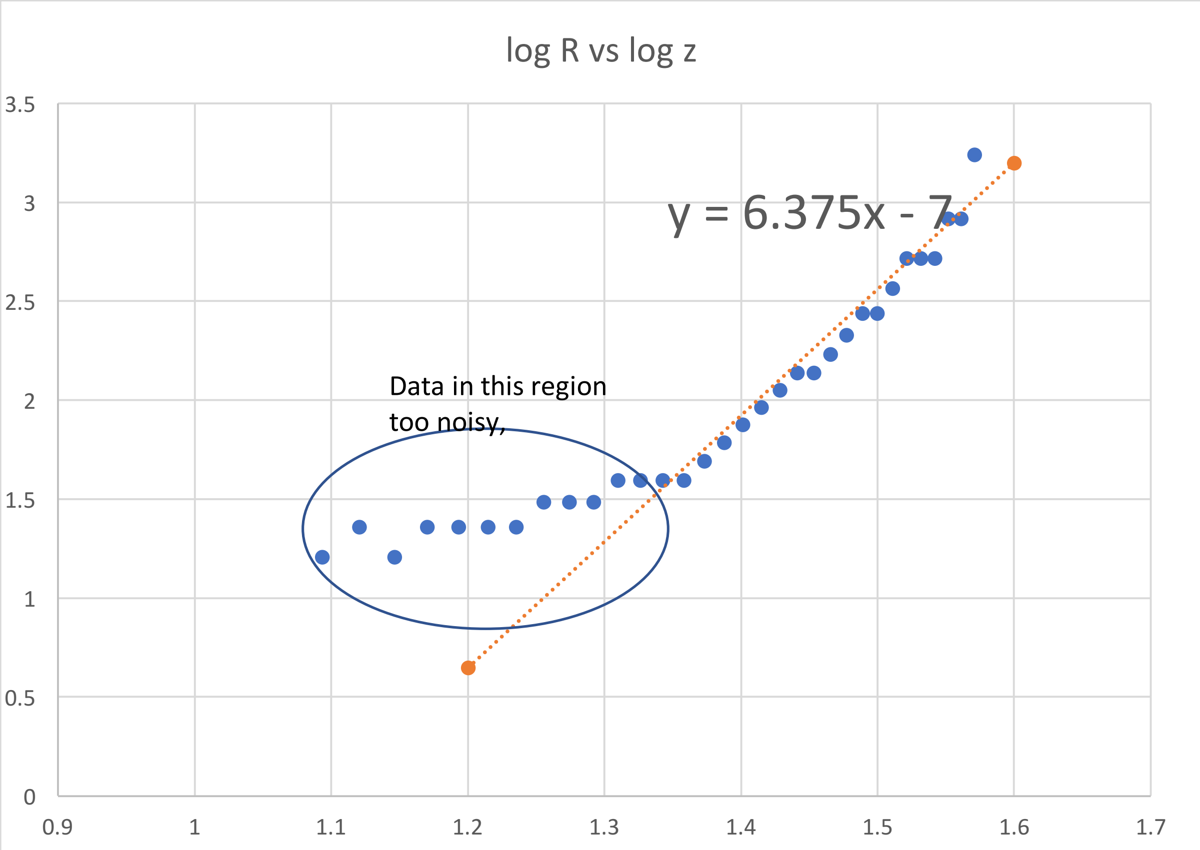
If a visual counting technique is used, at least three measurements are expected. If a turn-by-turn method, then distance measurements should be taken for at least three numbers of turns.

C2: Table of measurements:

turns	length of ligh	z (has offset)	M	R	z (corrected)	log z	log R
32.50	20.00	26.00	1.00	#DIV/0!	38.00	1.58	#DIV/0!
31.50	19.00	25.20	0.95	1748.00	37.20	1.57	3.24
30.50	18.00	24.40	0.90	828.00	36.40	1.56	2.92
29.50	18.00	23.60	0.90	828.00	35.60	1.55	2.92
28.50	17.00	22.80	0.85	521.33	34.80	1.54	2.72
27.50	17.00	22.00	0.85	521.33	34.00	1.53	2.72
26.50	17.00	21.20	0.85	521.33	33.20	1.52	2.72
25.50	16.00	20.40	0.80	368.00	32.40	1.51	2.57
24.50	15.00	19.60	0.75	276.00	31.60	1.50	2.44
23.50	15.00	18.80	0.75	276.00	30.80	1.49	2.44
22.50	14.00	18.00	0.70	214.67	30.00	1.48	2.33
21.50	13.00	17.20	0.65	170.86	29.20	1.47	2.23
20.50	12.00	16.40	0.60	138.00	28.40	1.45	2.14
19.50	12.00	15.60	0.60	138.00	27.60	1.44	2.14
18.50	11.00	14.80	0.55	112.44	26.80	1.43	2.05
17.50	10.00	14.00	0.50	92.00	26.00	1.41	1.96
16.50	9.00	13.20	0.45	75.27	25.20	1.40	1.88
15.50	8.00	12.40	0.40	61.33	24.40	1.39	1.79
14.50	7.00	11.60	0.35	49.54	23.60	1.37	1.69
13.50	6.00	10.80	0.30	39.43	22.80	1.36	1.60
12.50	6.00	10.00	0.30	39.43	22.00	1.34	1.60
11.50	6.00	9.20	0.30	39.43	21.20	1.33	1.60
10.50	6.00	8.40	0.30	39.43	20.40	1.31	1.60
9.50	5.00	7.60	0.25	30.67	19.60	1.29	1.49
8.50	5.00	6.80	0.25	30.67	18.80	1.27	1.49
7.50	5.00	6.00	0.25	30.67	18.00	1.26	1.49
6.50	4.00	5.20	0.20	23.00	17.20	1.24	1.36
5.50	4.00	4.40	0.20	23.00	16.40	1.21	1.36
4.50	4.00	3.60	0.20	23.00	15.60	1.19	1.36
3.50	4.00	2.80	0.20	23.00	14.80	1.17	1.36
2.50	3.00	2.00	0.15	16.24	14.00	1.15	1.21
1.50	4.00	1.20	0.20	23.00	13.20	1.12	1.36
0.50	3.00	0.40	0.15	16.24	12.40	1.09	1.21

1.0 points for the raw measurements of number of turns and M.
0.5 points for correct conversion to R.

Graph: **1.0** points for a graph allowing the calculation of the exponent.



0.5 for fit to correct region
0.5 for answer n within range 6 to 7 with reasonably estimated uncertainty.

Note: if students do not account for the distance between the surface of the stand and the surface of the fluid, the log-log graph will not have a proper linear region as it does not follow a reasonable power law. In this case there will be no credit for the conversion, the fit or the answer.

D1: Surface tension $\sigma \cong 2.3 \times 10^{-2}$N m^{-1}. **0.5** if within 10%, 0.3 within 20%, else 0.

D2: Table of sample measurements:

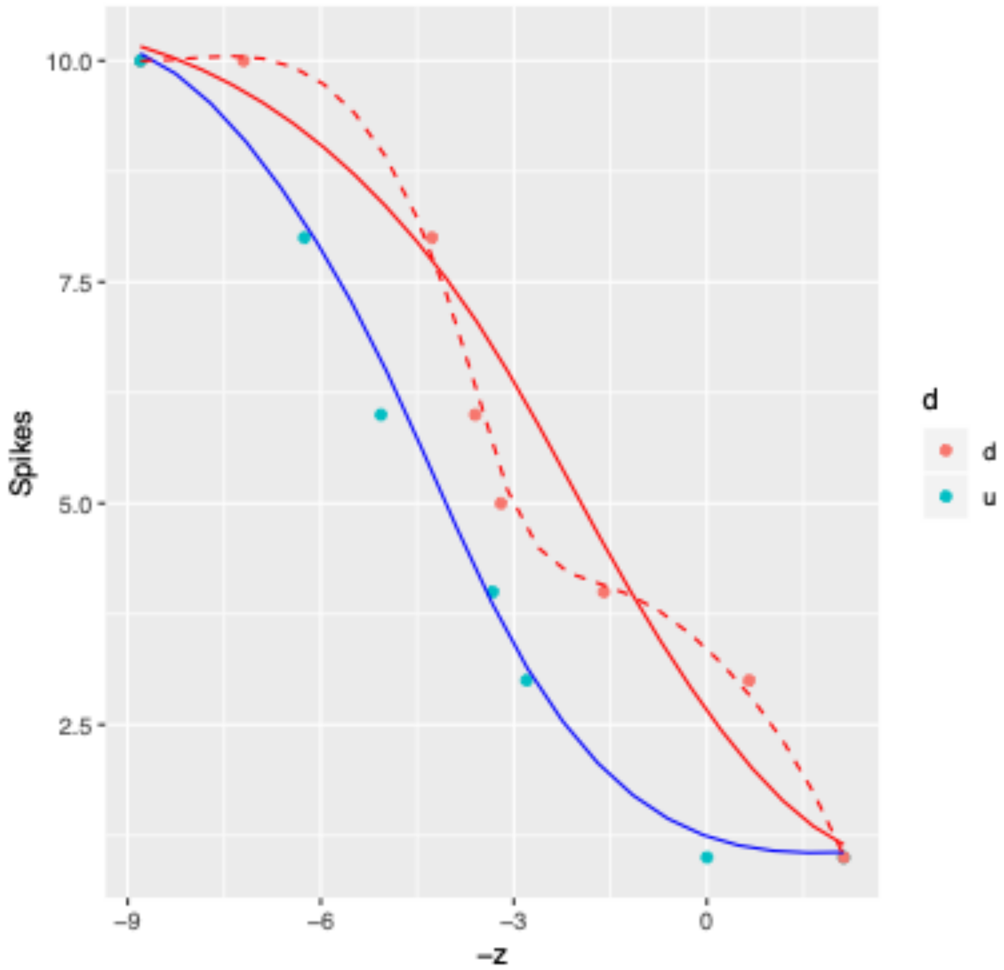
Spikes	Turns	z
1	0	0
3	3.5	2.8
4	4.16	3.328
6	6.33	5.064
8	7.82	6.256
10	11	8.8
10	2	7.2
8	5.66	4.272
6	6.5	3.6
5	7	3.2
4	9	1.6
3	11.82	-0.656
1	13.66	-2.128

In this data table, z has been measured to increase closer to the fluid; the question defines z to be the distance from the fluid. Students should either show explicitly how their variables are defined or transform to z as in the question. Either way, the graph in D3 must be in the appropriate direction and hence z transformed as necessary to match the question. In these solutions simply inverting z is used as the offset has no bearing on the hysteresis.

1.0 for at least 6 measurements each way, with conversion to z and a reasonable uncertainty estimate.

Note: this requires time and care to get the points of appearance and disappearance correctly. Missing values, or inaccurate jumps in spike number are indicative of sloppy work. Failing to use the calibrated screw thread (and instead using a ruler) renders the results significantly less accurate.

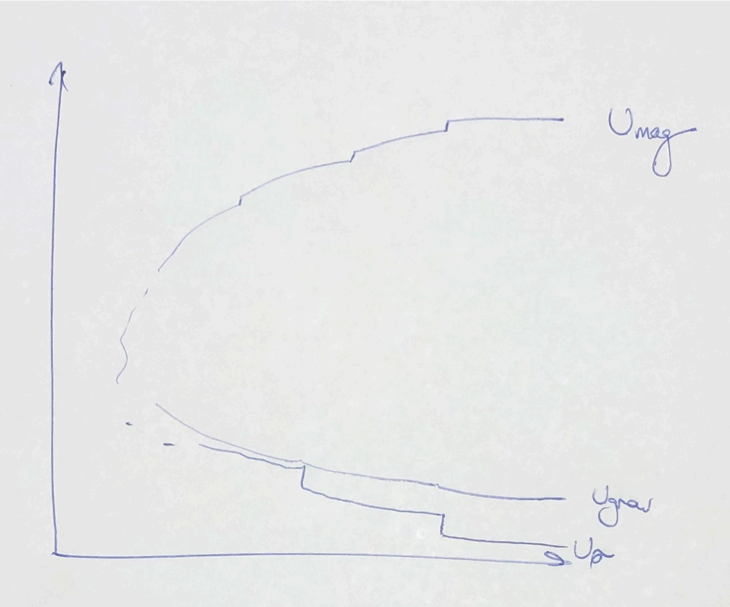
D3:



0.3 for a correctly plotted graph. 0.2 for each smooth curve fitting points. 0.3 if clear hysteresis shown: at least 1.5 mm separation in z between the up and down measurements.

Although the data are quantised they should still follow a reasonable curve. The curves shown above are blue for moving closer to the fluid, and red for moving away. The dashed curve is a likely result of a student joining points on the downward run – there is a waist in the data. The solid red curve is a typical averaging curve as seen at the APhO.

D4:



Key features:
Magnetic energy should decrease at a rapid rate as the magnet moves closer, following a power law – as long as it looks reasonable credit should be given without trying to determine the power. There should be small steps at the spike formations as there is a slight release of magnetic potential energy from the drawing of fluid along a new unstable surface.

Surface energy should jump at spike formation points and change much more slowly, although still steadily, throughout the rest of the time.

It is important that the overall energy decrease. Students should be able to tell this as the ferrofluid chamber will attract a magnet from underneath – most of the magnetic potential energy goes into lifting the magnet rather than being bound in the internal structure of the ferrofluid.

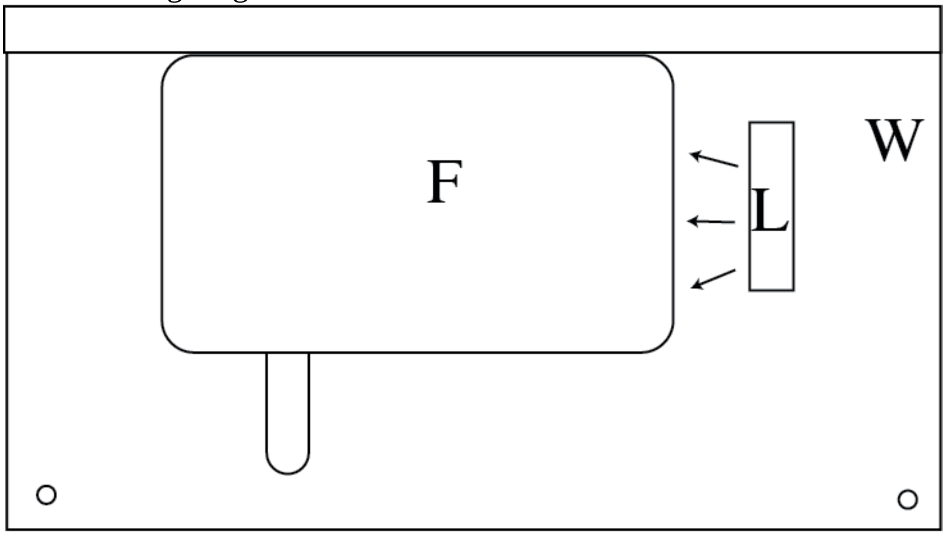
0.2 for each graph and 0.2 for correct behaviour of total energy.

Experiment
Q2 Wave pulses in a magnetically active fluid
Solutions

These quantitative values obtained depend strongly on the depth and other properties of the fluid, including how much oil has evaporated. The values mentioned in here correspond to the fluid as used at the APhO in Adelaide in May 2019.
Qualitative aspects of the solutions apply, even where values vary.

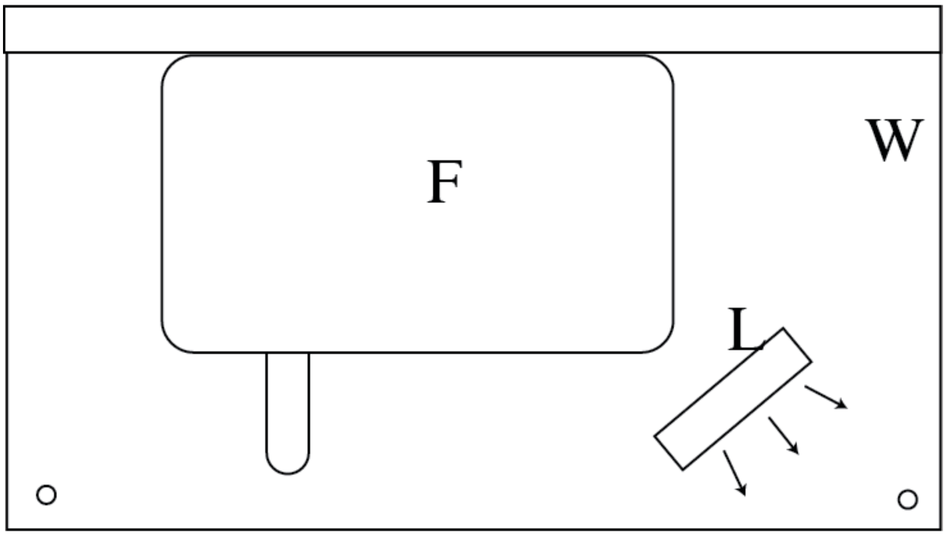
Throughout the light is used in two modes when taking videos. For parts A and D, the light is set up so that it is illuminating the ferrofluid surface through the sides of the box.

This direct lighting is used in Part A and Part F.



F – box with fluid
L – light
W – wooden base

Diffuse lighting is used for other parts. In this case the light is direction up and away from the box with ferrofluid.



Part A Plane pulses

A.1 Direct lighting was used, so see above for diagram.

A.2 Some example frames from videos are shown below.

Note that the scale on the graticule does not directly measure position.

A measurement with a ruler of the internal length of the container is 17.3 ± 0.3 cm.
The distance is equivalent to 13.4 graticule squares, so there is a factor of 17.0/13.4 to convert from graticule squares to cm.

The images above show two frames from a video of a plane pulse. The videos are recorded at 25 fps by default

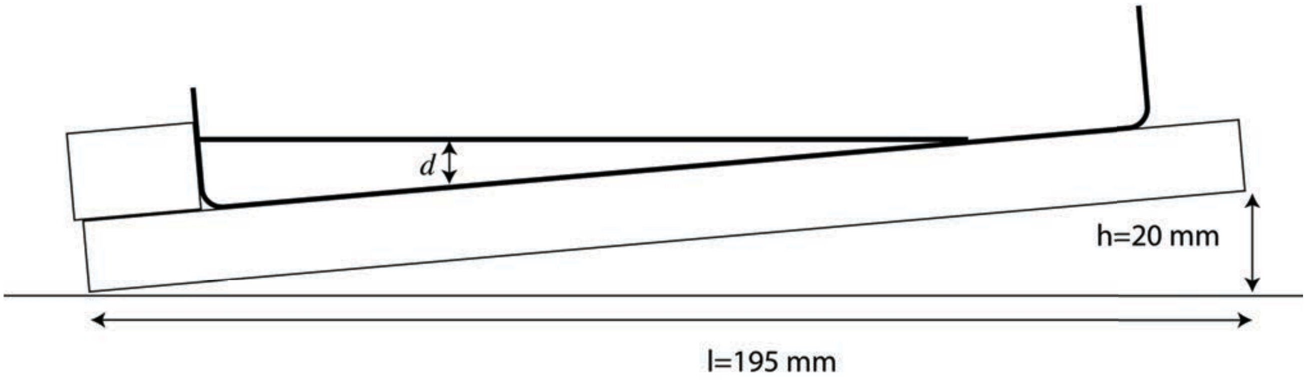
Frames	Distance (graticule squares)	Distance (m)	Speed (m/s)
8	6.5	0.83	0.26
7	6.0	0.76	0.27
9	6.8	0.85	0.24

This gives $v = 0.26 \pm 0.02$ m/s

A.3 The uncertainty is estimated from the spread of values.

Part B Wave pulses in fluid of varying depth

B.1
i.

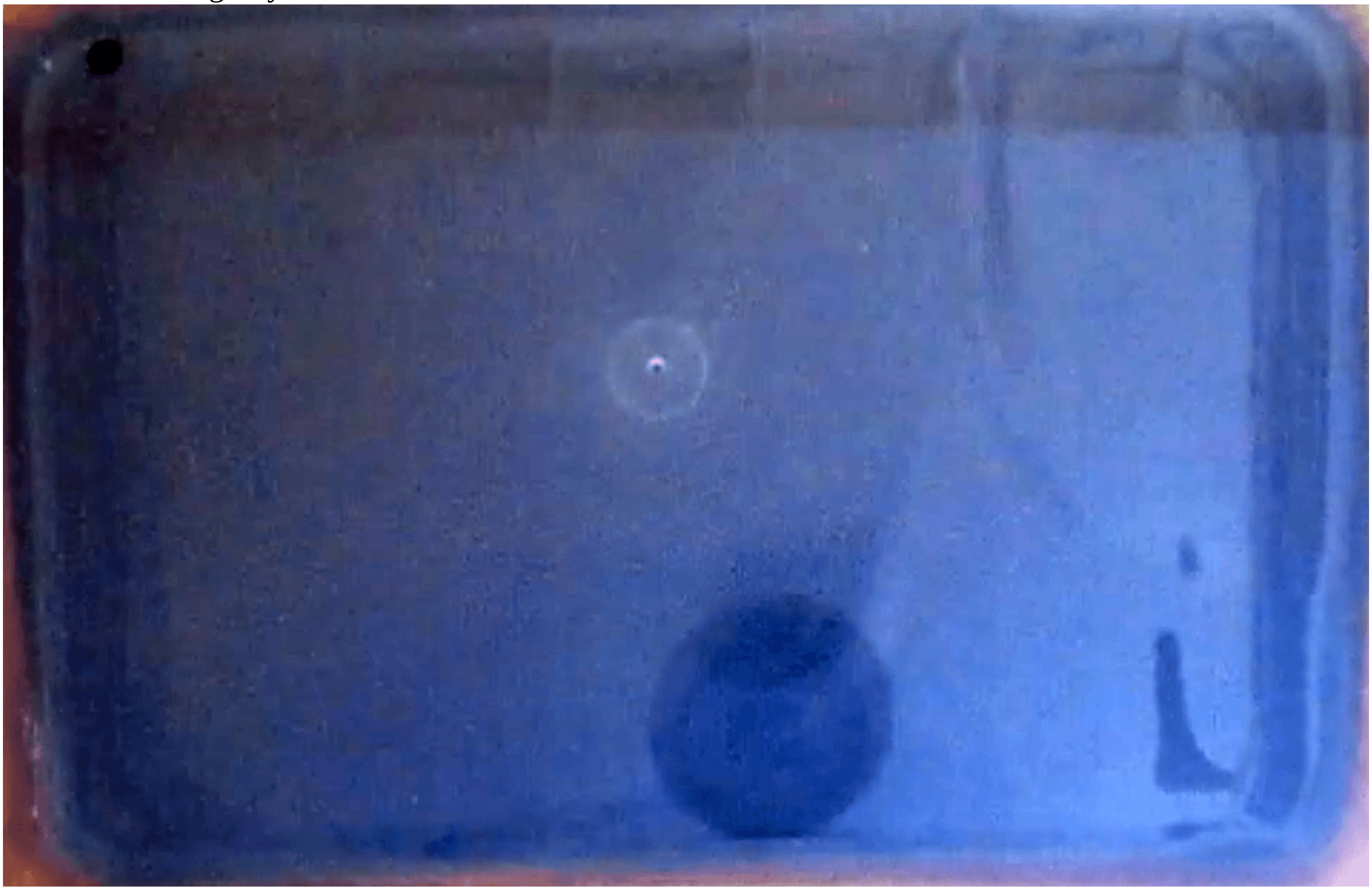


$h = 20 \pm 1$ mm, $l = 195 \pm 2$ mm. The latter uncertainty is larger due to difficulty lining up ruler with projection of end of the board.

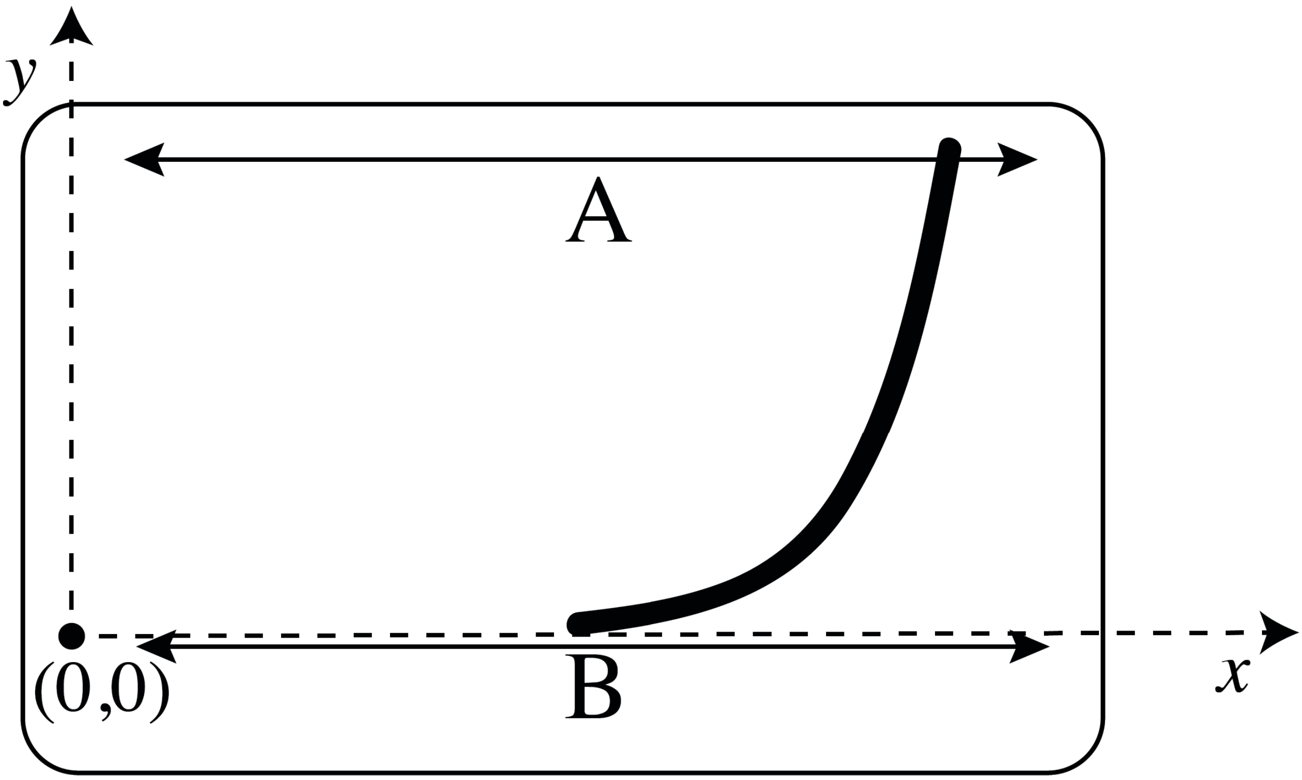
ii.
Since the depth varies linearly, $d = y\ tan\theta$.
Here $\tan\theta = \frac{h}{l} = 0.103 \pm 0.006$, so $d = 0.103\ y$.

B.2

A – fastest at largest y.

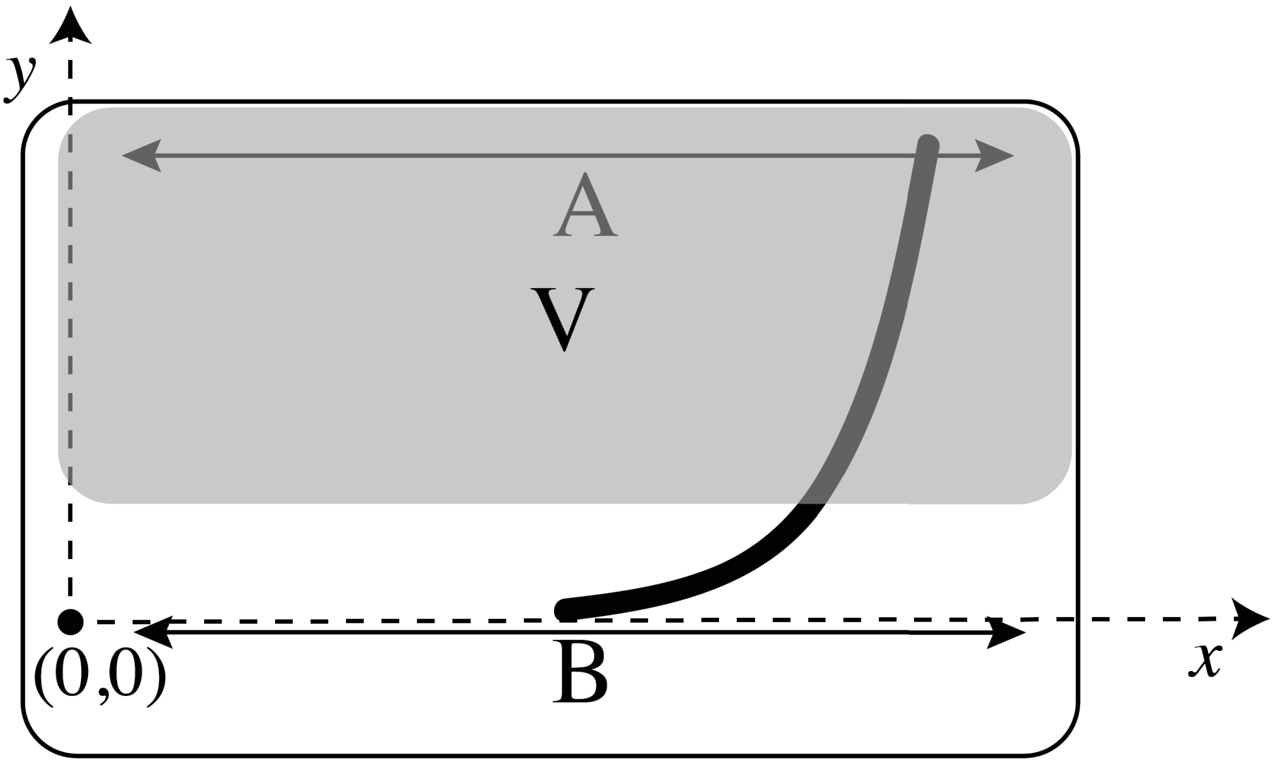


B – slowest at y=0.



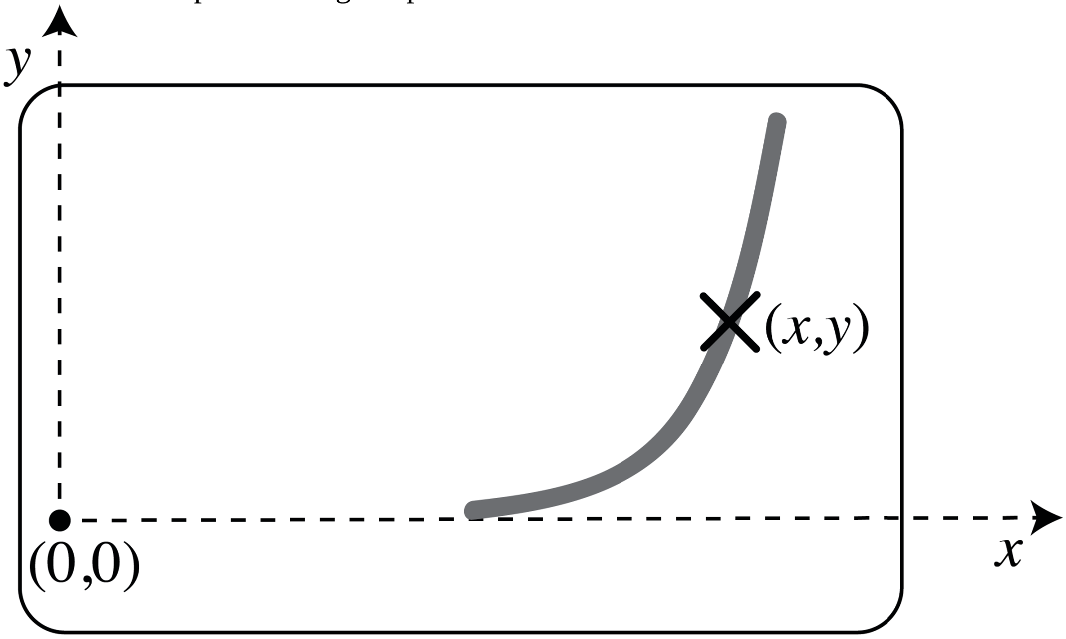
B.3 If x=0 when t=0, then $x = vt$, however, $v = \alpha\sqrt{d}$, so $x = \alpha\sqrt{d}t$.
Hence, $x = \alpha\sqrt{y \tan\theta}\, t$, or equivalently, $x^2 = \alpha^2 \tan\theta\, t^2 y$.
Here $\tan\theta = \frac{h}{l} = 0.103 \pm 0.006$, so $x = \alpha\sqrt{0.103y} \cdot t$.

This approximation will be least valid when the direction of propagation varies the most from the x-direction, and when the depth is least as there are nonlinear effects. Both of these happen for small y, in other words, $y < k$ for some constant k. This is shown as the grey shaded region marked V on the diagram below.



B.4 Diffuse light is more appropriate as the pulses are curved, so it is not possible to get direct reflections from the available source from enough of the pulse. See the second diagram on p. 1 for light position.

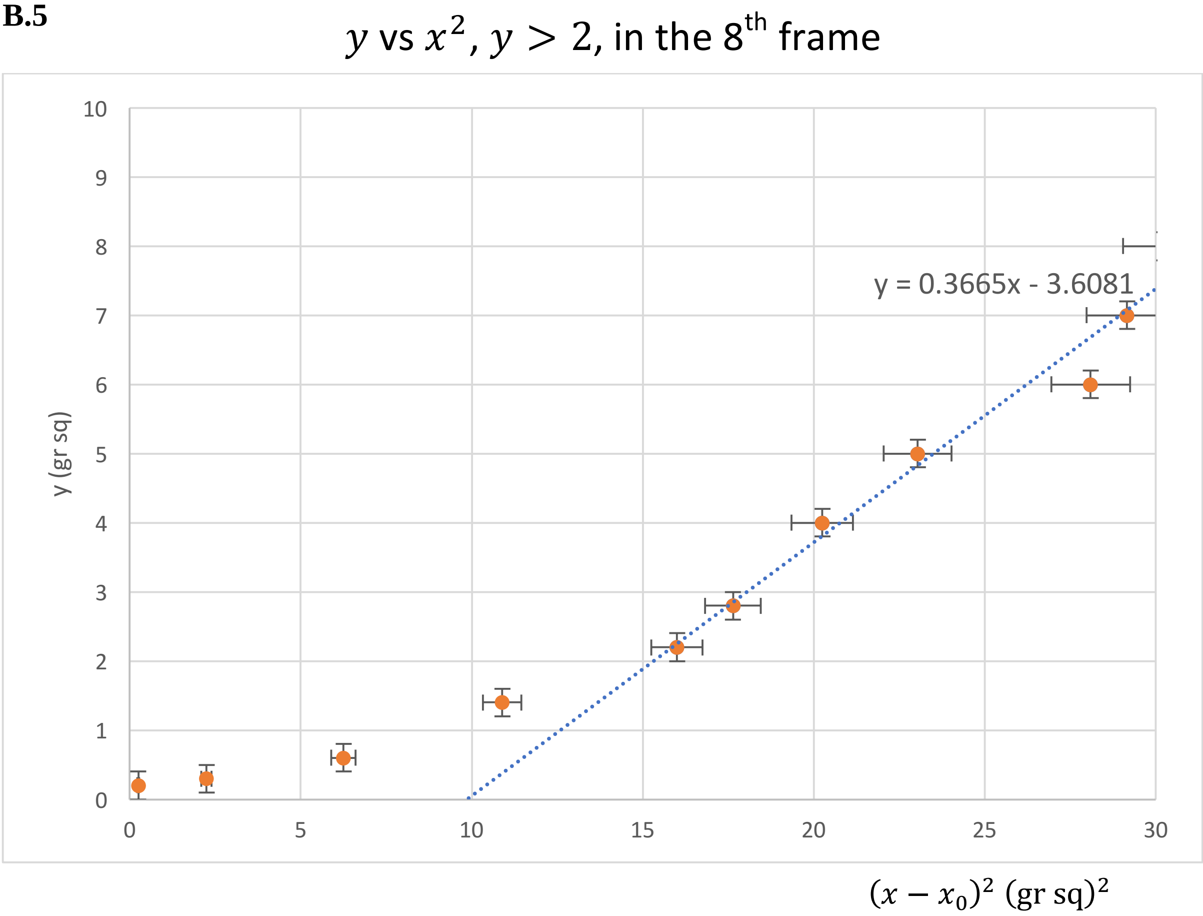
Videos of the curved pulses are recorded, with adjustments to the lighting, until a clearly visible pulse is observed near where the fastest travelling sections have reached the end. For that single frame the coordinates of points along the pulse are recorded.



The 8th frame after the generation of the pulse was used so $t = 8/25 \text{ s } = 0.28\ s$.
Here $x_0$is the x coordinate of the position where the pulse front is at y=0. This is treated as the new origin, and the offset in the $x = 0$ position is $x_0 = 4.5$ gr sq.

x (gr sq)	y (gr sq)	$(x - x_0)^2$ (gr sq)^2	$\Delta[(x - x_0)^2]$
5.0	0.2	0.25	0.02
6.0	0.3	2.25	0.15
7.0	0.6	6.3	0.4
7.8	1.4	10.9	0.6
8.5	2.2	16.0	0.8
8.7	2.8	17.6	0.8
9.0	4.0	20.3	0.9
9.3	5.0	23.0	1.0
9.8	6.0	28.1	1.1
10.0	8.0	30.3	1.2
9.9	7.0	29.2	1.2

B.5



Converting to SI units, the slope m = 0.280 /m.

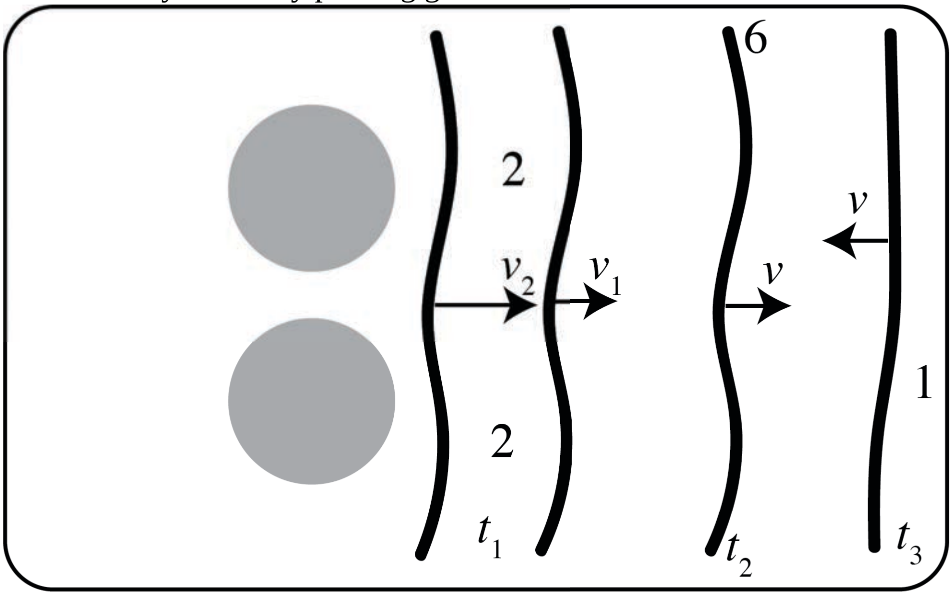
$$m = \alpha^2 \tan\theta\, t^2$$

Hence $\alpha = 5.9 \pm 0.5\ m^{1/2} s^{-1}$, and $v(d) = 5.9 \times \sqrt{d}$.

Uncertainty was calculated from the slope of the line of worst fit m = 0.331/m.

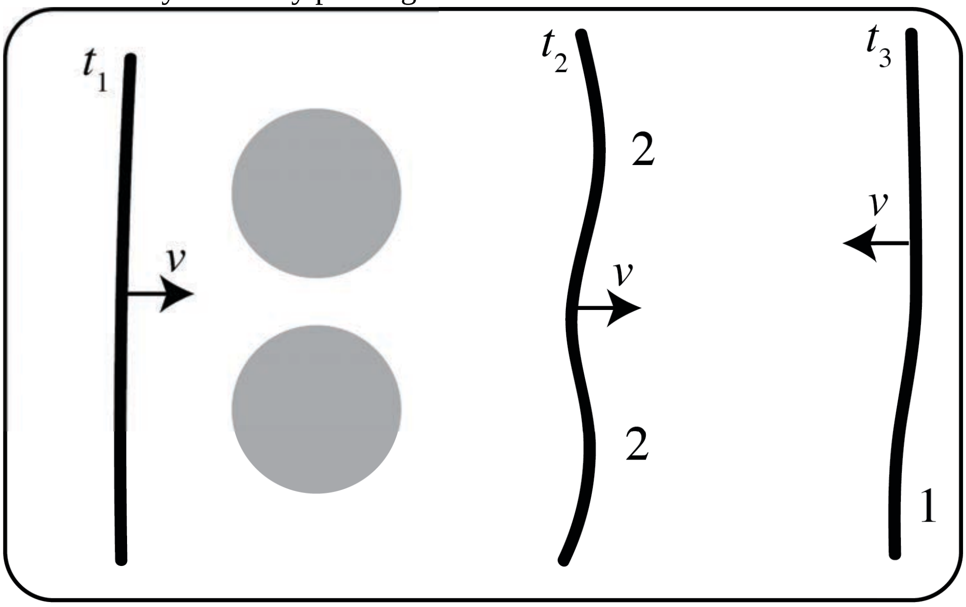
Part C Wave and magnetic effects

Mechanically driven by pushing glass



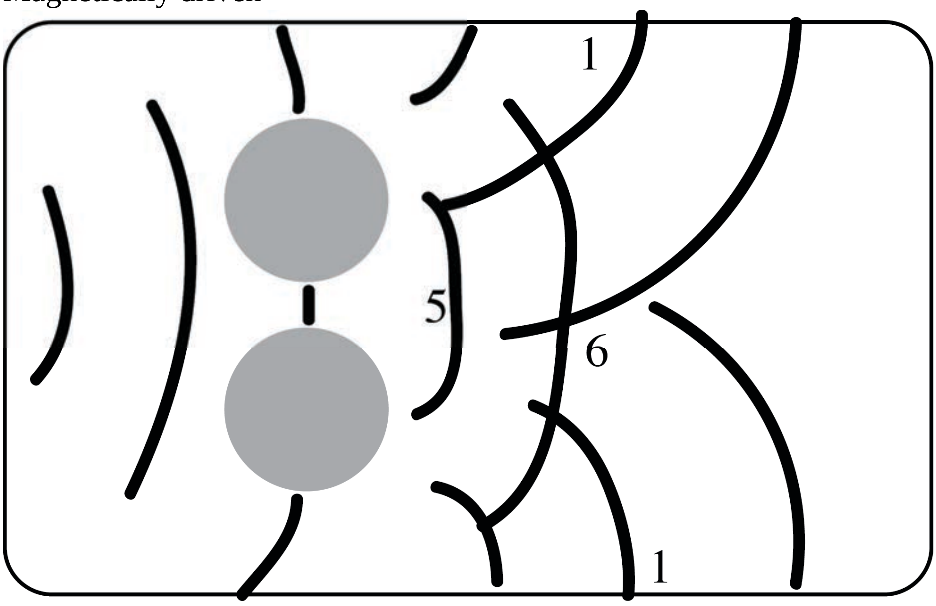
Refraction observed by perturbation of front over magnets,
Interference when the fronts meet,
Reflections from end.
$t_1 < t_2 < t_3$

Mechanically driven by pushing base



Refraction as wave is perturbed over the fronts,
Reflections from ends,
Maybe some diffraction after passing between the lumps over the magnets.
$t_1 < t_2 < t_3$

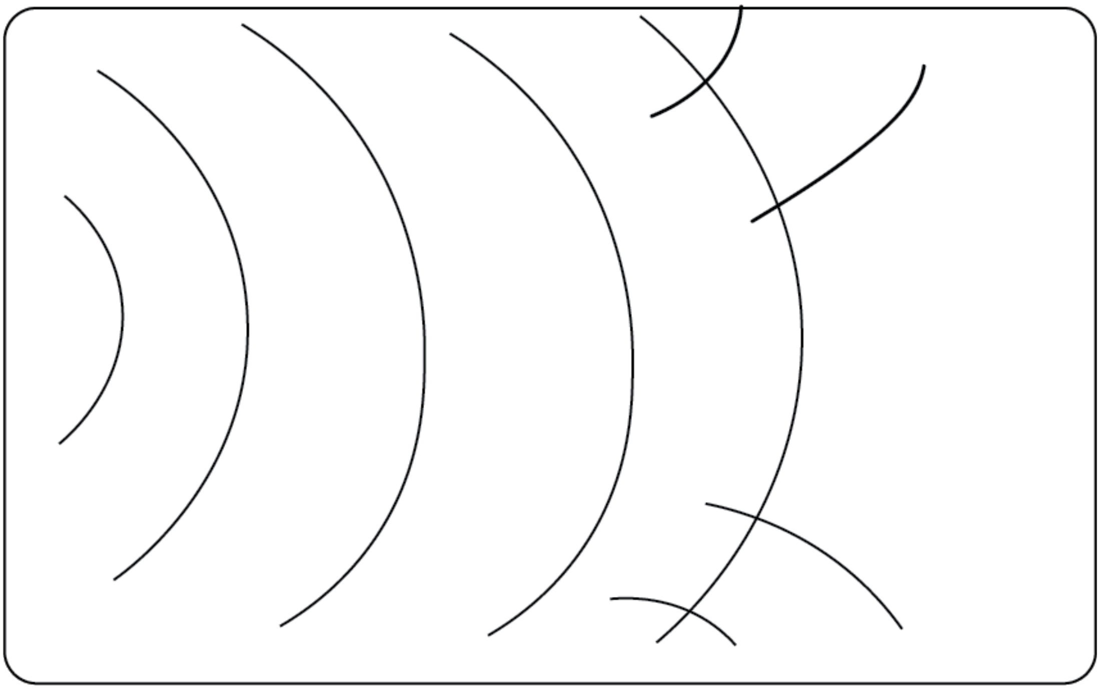
Magnetically driven



Reflections from side walls and ends
Diffraction after passing between the lumps.
Interference from many waves crossing.
Each line represents the position of a pulse front in a particular frame.

Part D Internal properties of ferrofluid within a strong magnetic field

D.1

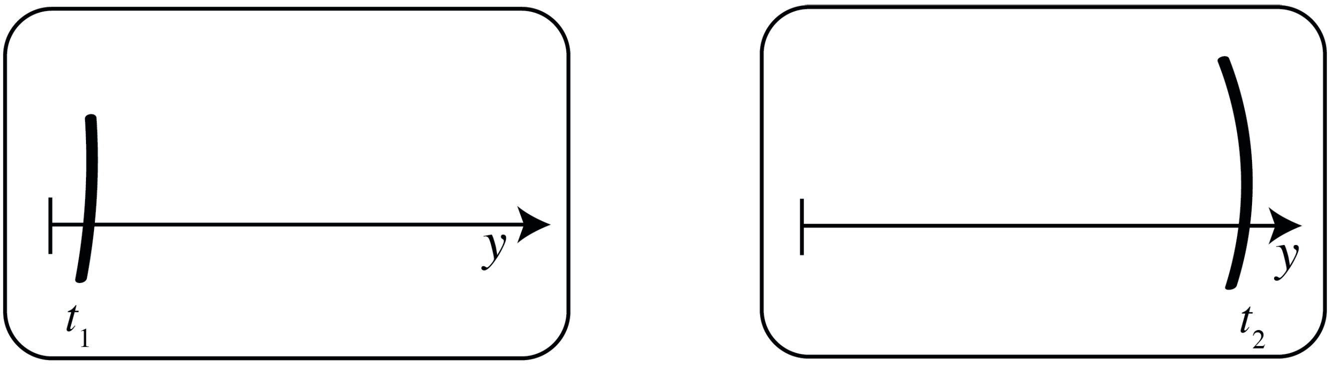


Magnetically driven pulses are not planar, so there is resulting reflection from the sides of the container. Note the multiple lines demonstrate the same pulse at different times.

D.2 Direct lighting, as in the first diagram on p. 1.

Speed measurements of the magnetically driven waves are around the same, to somewhat faster than small amplitude mechanically driven waves. Students should find that pulses are around 0.1-0.4 (gr sq)/m faster than in A2/3.

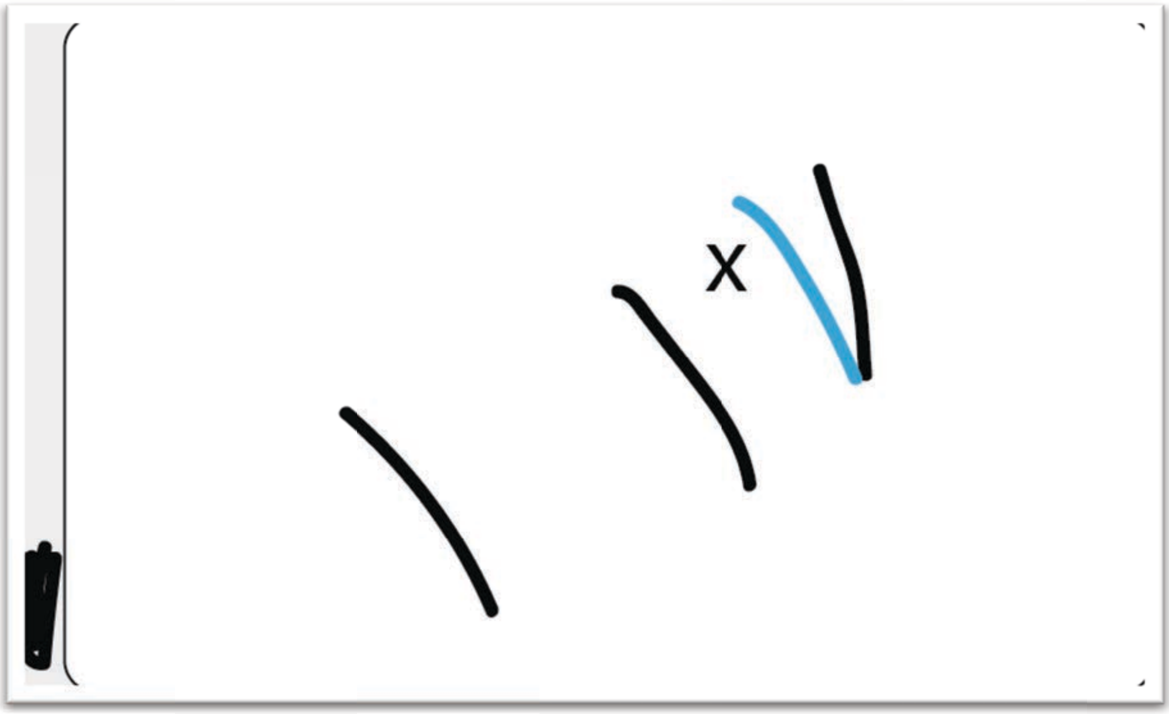
Data and sketches should look similar to A2/3 otherwise.



Measurements of the y position at two times, and the difference in the times allow calculation of the speed.

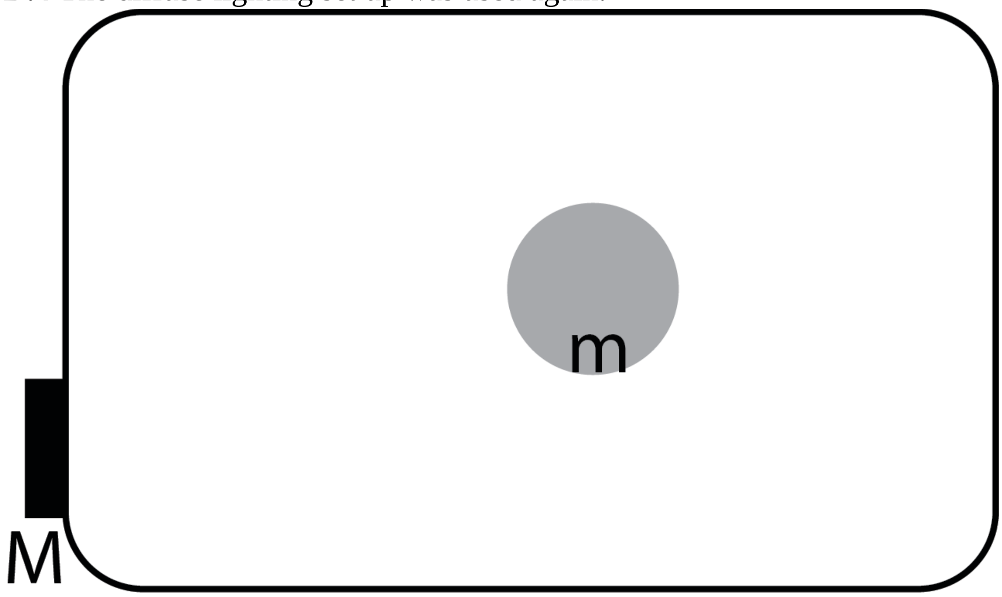
The height of the lump can be estimated by observing from the side, or more accurately by using the limiting value from E1 Part C.

D.3 The light was placed in the diffuse light set up. See the second figure on p.1.

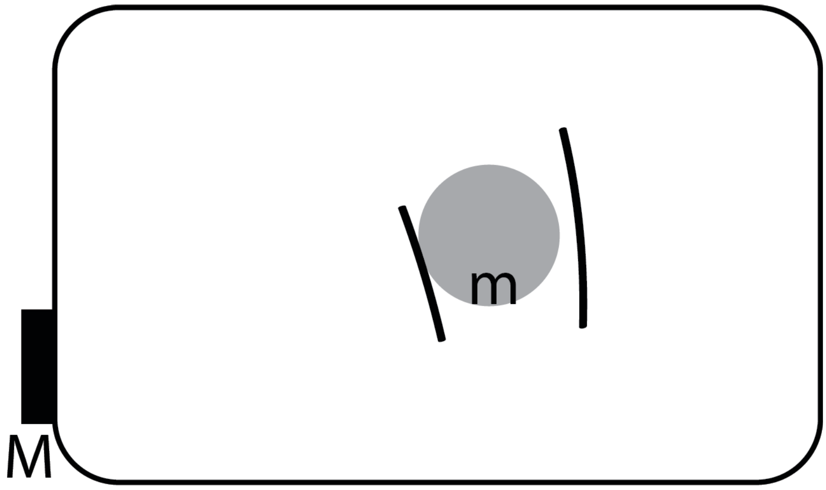


The black represents observed pulses over the magnet x. The blue represents the expected positionsing of the pulseafter travelled that distance.

D.4 The diffuse lighting set up was used again.



D.5
A wave front was observed to travel as additional 0.8 gr sq over 8 frames. The extent of the lump is assumed to be 3cm in diameter and the additional distance in the time all occurs over the lump. The wave crossed the lump in around 2 frames This means that the wave travels at a speed of around 0.35 m/s over the lump.



The two wavefronts shown above are only 2 frames apart.
Measurements of position were taken when the wavefronts where further apart.

D.6 The height of the lump can be estimated by observing from the side, or more accurately by using the limiting value from E1 Part C.
The best estimate of the height of the lump is found to be 5mm. The expected speed of fluid of depth 9mm, compared to fluid of depth 4mm is $\sqrt{\frac{9}{4}} = \frac{3}{2}$ times larger, which is $\frac{3}{2} \times 0.26 \frac{m}{s} = 0.39\ m/s$.

As these are estimates they are close enough that we cannot conlcude that the change in wave speed is due to anything other than the additional depth of the fluid.

E1. Static response of a magnetically active fluid
Marking scheme. Version 1.5a

Question part	Total marks	Partial marks	Explanation for partial marks and special cases
A.1	0.8	0.1 0.5 (0.2) 0.2	Diagram of a useful setup Full marks for z within range (0.070 ± 0.003)m For z within range (0.07 ± 0.01)m Uncertainty estimate (reasonable, <= 35%); if 2mm 0.1
A.2	0.8	0.3 (-0.1) (-0.1) 0.3 0.2	Correct formula $\Delta\rho g = 3\chi B_r^2 a^4 l^2/(8\mu_0 z^7)$ If measured a or l incorrectly instead of using given value (if good measurement of a or l, give full points) If $\Delta\rho$ out by ~10 but dimensionally correct No marks if dimensionally incorrect (eg. no g) Value of $\Delta\rho$=4.1 kg$\cdot$ m^{-3} (e.c.f. full marks for wrong z in A.1 – see figure) Uncertainty estimate (1.2 kg$\cdot$ m^{-3})
B.1	0.6	0.2 0.1 0.2 0.1	Value for $z_{crit} = 41 \pm 1$mm (or 22 ± 1mm full points using small magnet) Uncertainty for z_{crit} at most 2mm Value for $\lambda = 10 \pm 1$ mm Uncertainty for λ at most 2mm
B.2	0.6	0.3 0.2 0.1	Value for $\sigma = 1.0 \cdot 10^{-4}\ N \cdot m^{-1}$, correct with an order of magnitude (e.c.f. -0.1 for wrong Δ) Uncertainty estimate $\frac{\Delta\sigma}{\sigma} = \frac{7\Delta z}{z} + \frac{2\Delta\lambda}{\lambda}$ Relative uncertainty less than 70%
C.1	0.6	0.2 0.2 0.1 0.1	Diagram of a useful setup – needs to show clearly the measured quantity and the setup Measurements (at least 3) and calculations (0.1 for 1 measurement giving good value of for Δz) Value for $\Delta z = 0.80 \pm 0.02$ mm Uncertainty estimate <3%
C.2	3.5	1.0 0.5 0.3 0.7 0.5 0.5	Raw measurements for # of turns and M (1.0 for 18+ data points, 0.2 per 4 data points if <18, no points for changing l) Correct conversion to R Graph shows both regions Graph has 18+ correct data points (or if not 18+, 0.2 per 6 data points, plotted correctly) Good fit to correct region Answer n with range 6 -- 7 with uncertainty
D.1	0.5	0.5	Value for $\sigma = 1.1 \cdot 10^{-2} N\ m^{-1}$ • Full mark if within 30%, 0.2 – within 50%, else – 0
D.2	1.0	0.9 (0.6) (0.4) 0.1	5+ up, 6+ down 5+ up, 5+ down 4+ up, 4+ down No points if only in one direction Reasonable uncertainty estimate
D.3	1.0	0.3 (-0.1) (-0.1)	Correctly plotted graph No error bars if uncertainty in D2 large enough to plot Only one direction

		0.2 0.2 0.3	One smooth curve fitting points Second smooth curve fitting points Clear hysteresis shown: at least 1.5 mm separation in z (0.1 if separated by less, 0 if lines cross)
D.4	0.6	0.2 0.2 0.2	Correct graph for surface energy Correct graph for magnetic energy Correct step behavior for both graphs

Experiment
Q2 Wave pulses in a magnetically active fluid
Marking Scheme

Asian Physics Olympiad
Adelaide 2019

				TOTALS
A1	0.3	0.1	Ferrofluid in container	
		0.1	Light position and direction shown	
		0.1	Incudes at least one of camera, wooden base and hand to drive pulses	
A2	0.8	0.2	Sketch at least one pair of frames with important features and measurements	
		0.2	3 data points, raw data (0.1 for 2 data points)	1.3
		0.2	Calculate speed in m/s - including converting from whatever units were measured in the video	
		0.2	$v = 0.25 - 0.30\ \mathrm{m/s}$	
A3	0.2	0.1	Reasonable approach/formula	
		0.1	Up to 15% and consistent with method used.	
B1	0.3	0.1	Diagram	
		0.1	Measurements of h and l - no uncertainties no mark	
		0.1	$d(y) = \ y \tan\theta$ in terms of measured value of $\tan\theta$	
B2	0.3	0.1	A + B marked	
		0.1	Curve shape	
		0.1	Origin and axis orientation indicated somehow.	
B3	0.3	0.2	Relationship	
		0.1	V marked on B2 diagram	
B4	1.2	0.2	Diagram including set up for diffuse lighting	
		0.2	Choosing to fix t, as there is higher resolution in x and y	
		0.4	At least 10 coordinate pairs (0.2 for 6 coordinate pairs, 0.1 4 coordinate pairs)	3.4
		0.2	Uncertainties on data	
		0.2	Sketch of key frame with curve and coordinates marked	
B5	1.3	0.1	Convert to SI units	
		0.1	Choice of origin - $x = 0$ is not the edge of the container	
		0.1	Calculations of values to graph	
		0.4	Useful graph, accurate plotting, suitable labels (0.2 if t is not fixed on graph)	
		0.2	Uncertainties calculated and graphed	
		0.2	$\kappa = 4 - 7\ m^{1/2}s^{-1}$	
		0.1	Calculation of uncertainties	
		0.1	Uncertainty less than 15%	

C1	1.8	0.2	Sketch - showing two pulses, one catching the one in front, with perturbations around magnets	1.8
		0.3	2. over magnets, 6D. when fronts catch each other, 1. reflection off ends	
		0.2	Sketch - one pulse being refracted by two magnets	
		0.3	2. over magnets, 1. reflection off ends, 5. diffraction through gap	
		0.4	Sketch - sidewall reflection, lump refraction, interference everywhere, diffraction between lumps	
		0.4	1, 2, 5, 6d	
D1	0.2	0.2	More circular shape, and reflection off walls	3.5
D2	0.8	0.1	Diagram of set up, similar to A	
		0.1	Sketch at least one pair of frames with important features and measurements	
		0.2	3 data points, raw data	
		0.1	Calculations	
		0.1	Uncertainty in speeds	
		0.2	Speeds in range 0.26-0.31 m/s	
D3	0.4	0.2	Sketch with similar form to D1 before where the pulse crosses the region with the magnet	
		0.2	In region where it has crossed the magnet pulse should be ahead of where it would otherwise be	
D4	0.3	0.1	Diffuse lighting (or direct lighting, but only if the sketches of frames demonstrate it was appropriately aligned).	
		0.1	Graticule aligned with wave propagation direction.	
		0.1	Wooden base, fluid and magnets marked.	
D5	1	0.2	Sketches of frames with magnet lump region identified.	
		0.2	At least 3 data sets.	
		0.1	Calculations of time from frames	
		0.4	Time is in range 0.06 to 0.12 s	
		0.1	Uncertainty in time	
D6	0.8	0.1	Simple model of lump, e.g. cylinder.	
		0.3	Good estimates of dimensions of lump and depth of bulk fluid,	
		0.2	Calculation	
		0.2	Conclusion - probably ambiguous.	
			TOTAL:	10

Problems and Solutions: Acknowledgements

Final preparation of the problems was performed by Professor Vyacheslavs Kascheyevs, Dr Bonnie Zhang, Dr Alix Verdon and Dr Matthew Verdon with thanks for ideas, development and information variously from those listed below. Some key references are also provided for each question.

Theory

Q1: RF reflectometry for spin readout for silicon quantum computing

Thanks to Bentley Carr.

Inspired by the ARC Centre for Excellence in Quantum Computing and Communication Technology at UNSW.

M. G. House, I. Bartlett, P. Pakkiam, M. Koch, E. Peretz, J. van der Heijden, T. Kobayashi, S. Rogge and M. Y. Simmons, “High-sensitivity charge detection with a single-lead quantum dot for scalable quantum computation,” Physical Review Applied, vol. 6, no. 4, p. 044016, 25 100 2016.

T. F. Watson, B. . Weber, M. G. House, H. . Büch and M. Y. Simmons, “High-Fidelity Rapid Initialization and Read-Out of an Electron Spin via the Single Donor D(-) Charge State.,” Physical Review Letters, vol. 115, no. 16, p. 166806, 2015.

Q2: X-ray jets from active galactic nuclei

Thanks to Dr Paul Nulsen, Dr Bradford Snios and Dr Sarka Wykes

Harvard-Smithsonian Centre for Astrophysics

Sarka Wykes, et al. “A 1D fluid model of the CentaurusA jet”, Monthly Notices of the Royal Astronomical Society, Volume 485, Issue 1, May 2019, Pages 872-888,

https://doi.org/10.1093/mnras/stz348

Bradford Snios, et al.” Variability and Proper Motion of X-ray Knots in the Jet of Centaurus A”, accepted by ApJ

Bradford Snios, et al. “X-ray measurements of Superluminal Motion in the M87 Jet”

Q3: Tippe Top

Thanks to Professor Rod Cross, The University of Sydney.

Rod Cross, “Dynamics of a spherical tippe top”, European Journal of Physics, 39, 2018, 035001.

Stefan Rauch-Wojcichowski and Nils Rutstam, “Dynamics of an Inverting Tippe Top”, Symmetry, Integrability and Geometry: Methods and Applications, 10, 2014, 017.

Nils Rutstam, “Tippe Top Equations and Equations for the Related Mechanical Systems”, Symmetry, Integrability and Geometry: Methods and Applications, 8, 2012, 019.

Thanks also to Professor Shahraam Afshar, University of South Australia.

Experiment

Thanks to Professor Jamie Quinton and Tony Scoble, Flinders University.

For theoretical underpinnings of the experiment see, e.g., Rosensweig, Ronald E. Ferrohydrodynamics. Mineola, N.Y.: Dover Publications, 2018.

Asian Physics Olympiad

Adelaide, Australia | 5–13 May 2019

International Board Meeting Minutes

Minutes of the 20th Asian Physics Olympiad

Adelaide, Australia, May 5 – 13, 2019

1. A total of 165 students from 22 countries and territories participated in the 2019 Asian Physics Olympiad: Australia (8), Bangladesh (8), Cambodia (5), China (8), Chinese Taipei (8), Hong Kong (8), India (6), Indonesia (7), Israel (8), Kazakhstan (8), Macau (8), Malaysia (8), Mongolia (8), Romania* (8), Russia (8), Saudi Arabia (8), Singapore (8), Sri Lanka (7), Thailand (8), Turkey (8), UAE (4) and Vietnam (8).
   The number in parenthesis denotes the number of participants.

   * : invited as a guest team.

2. The final results of the APhO 2019 were presented to the International Board. The average of the top three contestants is 32.1, and twice of the median of all contestants is 32.8. According to the article #9 of the statutes of the APhO, the top three contestants is considered as 100%. The thresholds for all awards are

   28 point for a gold medal

   25 point for a silver medal

   20 point for a bronze medal

   16 point for honorable mention

   According to the above criteria, 9 gold medals, 16 silver medals, 33 bronze medals and 29 honorable mentions were awarded.

3. The following special prizes were awarded:
   - The Overall Winner Award : Grigorii Bobkov (Russia)
   - The Theoretical Winner : Ruoyu Yan (China)
   - The Theoretical Runner-up : Kangyao Chen (China)
   - The Experimental Winner: Rassul Magauin (Kazakhstan)
   - The Experimental Runner-up : Vladimir Malinovskii (Russia)
   - The Best Female Performer : She Ge (Singapore)
   - The Best Australian Performer : Stephen Catsamas (Australia)

4. The following President's award were presented :
   - The Association of Asia Pacific Physical Societies (AAPPS) for the Best Male Performer : Grigorii Bobkov (Russia)
   - The Association of Asia Pacific Physical Societies (AAPPS) for the Best Female Performer : Shu Ge (Singpore)
   - The Material Research Society (MRS) Singapore prize for the Most Creative Solution in Theoretical Exam : Grigorii Bobkov (Russia)
   - The Material Research Society (MRS) Singapore prize the Most Creative Solution in Experimental Exam : Chun-Wang Chau (Hong Kong)
   - The President Book Prize for the Most Deserving Male Student : Simon Yung (Australia)
   - The President Book Prize for the Most Deserving Female Student : Rosemary Zielinski (Australia)

5. On behalf of the International Board and all participants, the President of APhO expressed deep thanks to Dr. Matthew Verdon, Dr. Alix Verdon and all members of APhO 2019 academic committee for excellent preparation and executing of the 20th Asian Physics Olympiad. The International Board also thanked Ms. Ruth Carr, Ms. Tracey Byrne and many other people for their excellent logistic support. Our deepest thanks were also conveyed to Australian Science Innovation, as well as the supporting organizations, for hosting the 20th APhO.

6. International board also thanked Prof. Shang-Fang Tsai (Taiwan), Prof. Michael K.Y. Wong (Hong Kong) and Prof. Pavel Levchenko (Kazakhstan) for helping with the moderation.

7. President of APhO announced the new official website address of Asian Physics Olympiad: http://asianphysicsolympiad.org/ and asked for input from all international board members.

8. Arrangement of future hosting APhO is shown in the following list:

   2020 Taiwan confirmed

9. Delegate from Taiwan welcomed all delegates to Taipei for APhO 2020. The 21st APhO will be organized in Taipei, Taiwan from May 10 – 18, 2020.

10. The term for the president and the secretary of APhO will be expired next year. The current president, Prof. Leong Chuan Kwek, does not intend to serve as a president for the next term. The secretariat of APhO has approached three candidates : Prof. Chih-Ta Chia from Taiwan, Prof. Michael K.Y. Wong from Hong Kong and Prof. Ravi Bhattacharjee from India, and asked their willingness to serve as the president and all three nominations do not turn down the request. However Prof. Ravi Bhattacharjee suggested that election is not done by a voting, but through a discussion to keep a good atmosphere in the international board. The issued will be discuss through email and/or during the international board next year in APhO 2020.

_______________________ _______________________ _______________________

Prof. Leong Chuan Kwek	Dr. Hendra Kwee
President of APhO	Secretary of APhO

Newsletters

Asian Physics Olympiad
Adelaide, Australia | 5–13 May 2019

GRAVITAS

APhO 2019 NEWSLETTER
ADELAIDE, AUSTRALIA
VOL. 1 6 MAY 2019

Gravitas was inspired by the Latin word for 'Gravity', it being the fundamental force of nature that holds our universe together - much like the passion for physics that binds people of diverse backgrounds and aspirations at a momentous occasion like APhO.

G'DAY MATE

WELCOME TO AUSTRALIA

WELCOME

From the APhO 2019 Organiser

Ruth Carr

EXECUTIVE DIRECTOR,
AUSTRALIAN SCIENCE INNOVATIONS

It is a great honour for Australia to host the 20th Asian Physics Olympiad. We have planned an action-packed program that will see you doing challenging physics, cuddling koalas, kicking a 'footy', learning about our ancient culture, exploring the southern skies and much, much more. We wish you a fun, safe and rewarding week ahead.

FASCINATING ADELAIDE

CAPITAL OF SOUTH AUSTRALIA

As the APhO 2019 host city, Adelaide is proud to welcome delegates to the Land Down Under. Adelaide is South Australia's capital and its economic, educational and cultural hub. Filled with rich history and beauty, it has a lot to offer. Here some of the main attractions in this festival city waiting to be explored.

SOUTH AUSTRALIAN MUSEUM

For 150 years, the museum has celebrated Australia's cultural significance and natural heritage with its extraordinary collection of aboriginal artifacts and ancient animal fossils. A new initiative 'Her Story: Inspiring Women in Science', is another highlight of the museum showcasing female pioneers in the Science, Technology, Engineering and Mathematics fields.

ADELAIDE BOTANIC GARDENS

Nestled in the north-east corner of Adelaide city, the Adelaide Botanic Gardens are a wonderful escape from the stress of exams. Highlights include themed gardens featuring in-season exotic and native plants, an energy-efficient glasshouse collecting Amazon Waterlily, and the Bicentennial Conservatory fostering tropical rainforest plants endangered in their native habitats.

GLENELG BEACH

Situated but a mere tram ride away is Adelaide's favourite metropolitan beach, Glenelg Beach. Renowned for its stunning sunset, it offers visitors a buzzing vibe and entertaining atmosphere year-round. In 1931, the Glenelg Surf Life Saving Club was established and is today known as a life-saving icon located alongside the beach. You will learn some valuable lifesaving skills from these experts.

NURTURING PHYSICS' BRILLIANT MINDS

WITTAYA KANCHANAPUSAKIT

THAILAND

"I'm excited for the next few days. We trained the students for 4 weeks before coming here and we hope to bring some medals back to Thailand. But I told our students they don't need to do anything more to prove themselves in my eyes. I'm not going to judge them by the amount of medals they take back home. I really want them to enjoy their time in Adelaide and gain as much of experience as possible."

PRAMENDRA RANJAN SINGH

INDIA

"Whether it's the Asian Physics Olympiad or International Physics Olympiad, this is a great competition. We have trained our students well and hope for a couple gold medals like last year, but we want all the students participating to do well. Physics is a very challenging and interesting subject. So if they do well in this subject they will be successful in their life too."

KIMLEANG KHUN

CAMBODIA

"It's great to be part of APhO and to be here in Adelaide, especially at this time when we get to enjoy the cold weather. Coming from Cambodia where it's 40°C, even the students are excited. With the competition, we don't want them to be afraid and told them to just work hard to do their best."

NITZAN ARTZY

ISRAEL

"We've been preparing the students for a year, sending them homework while conducting training. I just hope the students will have a great time meeting each other, enjoying the competition and possibly see some kangaroos and koalas. The most important thing they can do is meet other people and get to know them."

GEARING UP FOR ASIA'S TOUGHEST PHYSICS COMPETITION

LIM POH SENG
MALAYSIA

“What excites me the most is the excursions during this trip and the exams because this is a competition that not everybody can have the chance to participate in. So it’s a real pleasure for me to get a chance to be in Adelaide.”

RUOYU YAN
CHINA

“I am very excited about making some new friends in APhO. In terms of the team preparation, we’ve reviewed exam papers from previous years and done lots of other practices. We even skipped the public holidays in China and focused on our preparations instead. As the Chinese team performed very well in APhO in the past two years, we are making every effort to meet the expectations.”

KHEM RAKSA PEOU
CAMBODIA

“I am looking forward to a little bit of everything, the food, animals and Australian lifestyles. This is a once-in-a-lifetime opportunity for me. Of course we’ve prepared a lot for the exam, and our focus is probably more on the exam, but the exam is not everything. We also want to make new friends and experience what Australia has to offer.”

KHANH LINH NGUYEN
VIETNAM

“I want to see the unique animals in Australia because they are so different from the animals in the northern hemisphere. Also, I am most looking forward to the experimental exam. I know that Australia has lots of advanced technology. Hopefully, some high-tech elements or cutting-edge inventions will be involved in the experimental exam."

IVANDER JONATHAN MARELLA
INDONESIA

"We will focus on the exam and try to achieve the best possible result. We want to get as many medals as we can. Apart from that, we seek for new experiences and want to make new friends across the countries. I believe this APhO event will be a memorable experience for all of us, both for students and team leaders.”

LAPHAS PREMCHAROEN
THAILAND

“I look forward to making like-minded friends who are interested in physics and expanding my knowledge in physics. After the exam, I would be able to know what’s my weak point and fix it. For our team, we had a physics camp for a month, where we studied physics in classes and practiced previous exam papers from many years ago.”

AUSSIE WORD OF THE DAY

In Australia, the good old Land Down Under, we have a reputation for having some of the oddest slang words that may be downright confusing. But we love 'em and we reckon you will too. So while you're immersing yourself in Adelaide's sights and sounds during the APhO 2019, why not pick up a few words?

'GOOD ON YA'

Here's one you'll hear pretty often. It is an Aussie way of saying 'well done'! Try it out and give your friend an Aussie compliment next time he/she does a good job!

WEATHER

Sunny and clear

High 19° Low 11°

JOIN THE CONVERSATION

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ACKNOWLEDGEMENT OF COUNTRY

Kaurna miyurna, Kaurna yarta, ngadlu tampinthi

The Asian Physics Olympiad Committee acknowledges that we are meeting on the traditional country of the Kaurna people of the Adelaide Plains. We recognise and respect their cultural heritage, beliefs and relationship with the land. We acknowledge that they are of continuing importance to the Kaurna people living today.

Photo credit: Adelaide Convention Centre

STAGE IS SET

NOT-TO-BE-MISSED PERFORMANCES AT THE OPENING CEREMONY

We are finally here: the Asian Physics Olympiad 2019, a year in the making, right from the bidding process to organising and guest arrivals, today Adelaide is hosting some 250 visitors from 22 countries at this coveted event.

The stage is set to welcome all international delegates today, highlighting South Australia at its best, starting with the showcase of Adelaide's cultural heritage and local dancers.

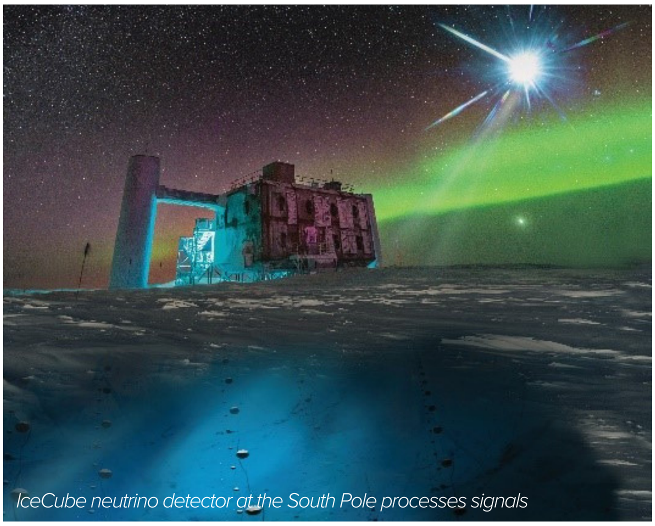
Following this, guests will hear from distinguished speakers, some of whom have been called more than experts in the field of physics.

ADELAIDE INSIDER

Brought to you by The University of Adelaide

TODAY'S SNEAK PEEK

Physics at The University of Adelaide



IceCube neutrino detector at the South Pole processes signals

We hope you are as excited as we are about the chance to live and breathe physics for a whole week.

Like you, we are on a quest to understand the world around us, the world inside us and the world beyond us through physics.

Our world-renowned scientists are experts in their fields and their ground-breaking discoveries capture international attention in the world's best research journals.

We are ranked in the top 135 in the world for physics and astronomy.* We collaborate with national and international partners on cutting-edge global physics projects.

In fact, we were one of three universities in the world to be involved with finding the Higgs boson at CERN, astrophysical neutrinos by IceCube, as well as the Nobel Prize-winning discovery of gravitational waves by LIGO. And University of Adelaide students were part of all three projects.

We are active across a wide range of research areas, with our researchers at the forefront of discovery in astronomical and space sciences; atomic, molecular, particle and plasma physics and optical physics. So good luck for this week. We look forward to sharing the wonder that this fundamental science has to offer this week.

*Times Higher Education, 2019

Asian Physics Olympiad
Adelaide, Australia | 5–13 May 2019

GRAVITAS

APhO 2019 NEWSLETTER
ADELAIDE, AUSTRALIA
VOL. 2 7 MAY 2019

Gravitas was inspired by the Latin word for 'Gravity', it being the fundamental force of nature that holds our universe together - much like the passion for physics that binds people of diverse backgrounds and aspirations at a momentous occasion like APhO.

CEREMONIAL WELCOME

Printed by Toshiba

INSIDE

ENTHRALLING INDIGENOUS PERFORMANCE

Audience taken on a journey of rich cultural history

EXAM PREPARATION

What went into putting the students to the test

SCHOOL VISITS

Peek into the life of an Australian student



OPENING CEREMONY
HIGHLIGHTS


Some 250 delegates witnessed yesterday the official opening of the Asian Physics Olympiad here in Adelaide. The ceremonious event, which kicked off on a high note, certainly left the room energised and ready for the journey that awaits this week.

First up was a beautiful Welcome to Country by Jack Buckskin, a Kaurna and Narrunga man. This symbolic ceremony, performed by an Indigenous Australian Elder to welcome visitors to their traditional land, takes many forms. Jack used the traditional Didgeridoo in hopes of continuing the tradition of playing the world's oldest instrument in the 21th century.

Attendees also received some wise and encouraging words by esteemed speakers, among them were Australia's former Chief Scientist Professor Ian Chubb AC, South Australia Chief Scientist Professor Caroline McMillen and Professor Fred Watson, Australia's Astronomer-at-Large.

In welcoming the students to Adelaide, these science powerhouses also expressed their pride in standing before some of the best talent who are poised to be the future game changers.

The entire affair would not have been the same if not for the energetic dance performance by the Cheryl Bradly Dance Troupe. Grooving to the tunes of Bruno Mars, the troupe truly ended with a bang, uplifting the crowd.

ALL HANDS ON DECK

Preparing for Asia's toughest physics competition requires collective effort from various heavyweights.

Yesterday, Team Leaders, Observers and Volunteers were involved in the tedious task of going over the theoretical physics examination papers students spent months preparing to ace in this competition. In this process, done within each country group, participants start by reviewing the exam questions followed by open discussions and votes on whether the questions are to be kept, changed or removed. Once this has been decided and finalised, translation of the papers takes place with this whole process often being an all-nighter. At the Adelaide Convention Centre, the exam hall setup is now complete. We wish all students the best of luck for the first exam this morning.


AUSSIE SCHOOL LIFE

Yesterday afternoon, delegates spent their afternoon visiting 10 schools in Adelaide such as the Adelaide High School, St Peter's College and Unley High School. The Australian and Israeli teams had an exciting trip to Pembroke High School, where our Physics Olympians got a taste of the Australian school culture as some hand-balled a footy for the first time, had their first unforgettable Vegemite biscuit, Lamingtons and TimTam bites, and some simply enjoyed the beautiful campus tour.

Along with his students, the school's Head of Science Graham Duffy extended a warm welcome to our delegates and kicked off the school visit by introducing the popular Australian Rules Football, fondly known as footy. After the Aussie sporting experience, APhO students got the chance to see the physics lab and joined Pembroke students to work on some hands-on activities to measure voltage and current for a resistor and apply the Ohm's Law to work out the resistance. This was followed by a campus tour filled with good times.

ROSEMARY ZIELINSKI

AUSTRALIA

"It's very interesting to see what Australian schools look like in other states, and more importantly, it's very enjoyable showing other people your country, like what your school is like, even though it's not my school. Half of the fun is meeting other teams. We've been playing lots of games with the Israeli team, and just exchanging about what life is like being a school student."

ERAN MANN

ISRAEL

"I love swimming, tennis, jogging and frisbee. I've played American football once or twice, but I have never kicked a football in this way. So, it's definitely a new experience and it's already a lot of fun. I wish we would get more chance to play it during our time here."

GRAHAM DUFFY

HEAD OF SCIENCE

"Our school is very internationally-focused that we have a boarding house with students from all around the world. Our community is also very international that we have teachers coming from different parts of the world.

"We teach South Australian Certificate of Education (SACE) and International Baccalaureate (IB). Through the IB, we are connected to schools all around the world. We do believe that it's important to keep these connections open. That's part of the reason why we want to be part of APhO 2019."

AUSTRALIA'S PHYSICS TRAILBLAZERS

Before the ultrasound become a routine procedure in prenatal check-ups, pregnant mothers had been using X-rays to obtain health information of their unborn babies. Exposure to the radiation that could harm a baby's development was of great concern.

In 1961, an Australian ultrasound research group led by David Robinson and George Kossoff made an extraordinary breakthrough in the area of diagnostic ultrasound and built the world's first commercially practical ultrasound scanner. The radiation-free ultrasound scan utilises high-frequency sound waves to capture live images of the baby. Nowadays, the diagnostic technique not only makes birth much safer for mothers and babies but plays a significant role in examining other internal body structures.

AUSSIE WORD OF THE DAY

'RECKON'

To mean 'think' or 'assume, here's another Aussie slang word to add to that dictionary.

E.g. What do ya reckon? / I reckon the weather tomorrow will be good enough to go to the beach!

WEATHER

Rainfall

High 18° Low 11°

JOIN THE CONVERSATION

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ACKNOWLEDGEMENT OF COUNTRY

Kaurna miyurna, Kaurna yarta, ngadlu tampinthi

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HAPPY BIRTHDAY!

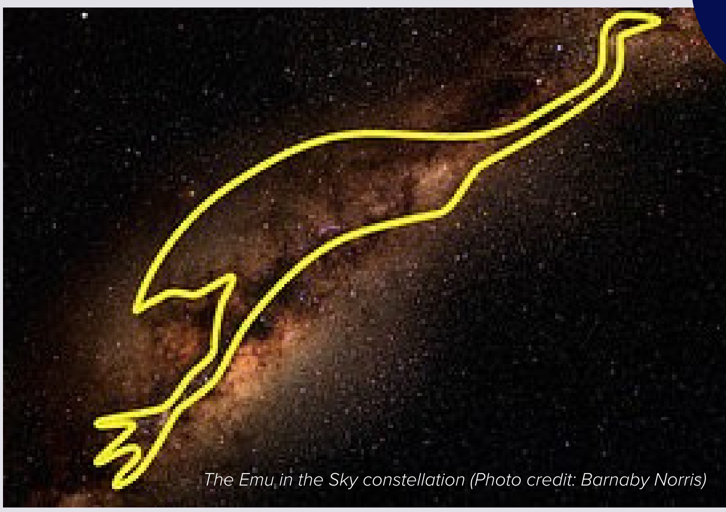
LE QUANG HUY	LE VIET HOANG	GUO XUBO
Student, Vietnam	Student, Vietnam	Observer, China

ADELAIDE INSIDER

Brought to you by The University of Adelaide

TODAY'S SNEAK PEEK

INDIGENOUS ASTRONOMY



The Emu in the Sky constellation (Photo credit: Barnaby Norris)

Astronomy is not a new field. For tens of thousands of years, humans have been looking to the sky for meaning.

To the ancient Egyptians, the stars were gods and goddesses, whereas the ancient Chinese tended to use astronomy for practical purposes, such as timekeeping.

The First Nations people of Australia have been blending science with storytelling for over 65,000 years; making them the oldest astronomers in the world.

Unlike Greek celestial practice, which focuses almost wholly on stars, Indigenous astronomy focuses on the dark patches between the stars. An example of this is the story of the Emu in the Sky constellation.

You can spot the emu by looking south to the Southern Cross; the dark clouds between the stars is the head, and the neck, body and legs are formed from gas and clouds stretching across the Milky Way.

According to Indigenous legend, emus were creator spirits that used to look over the land.

The position of the emu in the sky indicates when to collect emu eggs, and it is well known amongst Indigenous groups across Australia.

The Kaurna people (the traditional custodians of the land that the University of Adelaide is located on) saw the same dark patches as a large river where a Yura (monster) lives in the dark spots.

This knowledge is a living part of Indigenous cultures and continues to evolve.

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RISING TO THE CHALLENGE

Printed by Toshiba

INSIDE

EXAM MODE ON

Theoretical exam challenges delegates to the next level

KAURNA PEOPLE

Meeting the traditional owners of the land and learning their heritage

TASTY TOUR

Discovering Adelaide like a local on a market tour

*NINNA MARNI**

HELLO, HOW ARE YOU?

Upon finishing their first major challenge of the APhO competition, students were yesterday taken on a beautiful journey through the culture and practices of Australia's Indigenous people.

At the South Australian Museum, some were treated to an introduction to Ethnoastronomy of Australia's First Peoples, while others kicked off the experiential journey by walking through the Australian Aboriginal Cultures Gallery.

Indigenous astronomy dates back tens of thousands of years, naming them the oldest astronomers in the world. They have been known for developing ways to observe the Sun, Moon and stars to help with navigation and predict the weather.

One kilometre away, at the Adelaide Botanic Garden, a second group of APhO students were being taken through a different journey of Adelaide's history. The gardens are home to some endangered plants, one of them being the 'Wollemia nobilis' or Wollemi Pine, which was said to have been in existence since the Mesozoic Era.

Students were also taught about the wetlands at the garden's First Creek Wetland, which functions as a water sustaining system for the Adelaide Botanic Garden.

**Kaurna language*

DELEGATES SHARE THEIR THOUGHTS ON THE EXPERIMENTAL EXAM

SABINA DRAGOI

ROMANIA

“The theoretical exam has three problems and one of them was mechanics, but it was pretty challenging because it has three different reference systems and we need to choose which one to use. The other question was related to quantum computing, and the final one was about super productive astronomical jets involving protons and particles."

NISARG PRATIKKUMAR SHAH

UNITED ARAB EMIRATES

“I guess 5 hours is a reasonable amount of time to solve the questions and I thought the exam was of moderate difficulty level for me. I found the mechanical part not too hard as it’s where my interest lies. I feel I could score higher in the experimental exam. On the theoretical side, we'll just have to wait to find out."

ITGEL DELGERDALAI

MONGOLIA

“Although all the questions were quite challenging, I am not too concerned about the results as I tend to enjoy the unique experience of the exam itself. I found all the questions were quite interesting. As some of the topics that came up in the exam have been covered before in our preparation, they were well within our expectations."

PHYSICS OLYMPIAN RETURNS AS A VOLUNTEER

This is Yongqin’s second time being a part of APhO, only this time she isn't competing. “It’s still very exciting, but a bit weird because I was at the front of the exam hall where I could see all the students in today’s exam,” said the former Physics Olympian who represented Australia at APhO 2018 in Vietnam. For Yongqin, her experience last year was gratifying, driving her to return as a Volunteer instead. “We had such a great time last year. I felt it would be good to give other people the same experience in Adelaide,” she said.

As a Team Guide for delegates from Taiwan, she's proud of them and believes that they carry the spirit of APhO. “They’re all passionate about physics and get along very well with each other. Though they've just met, they bonded really well as a team, which is very nice to see as that’s what APhO is all about," said Yongqin.

AUSTRALIA'S PHYSICS TRAILBLAZERS

Adelaide-born Astronaut, Dr Andrew Thomas, became the first Australian to participate in a space research mission in 1996. He found his passion in space when he was a young boy building rockets with paper cardboards. In 1973, he received a Bachelor of Engineering with First Class Honours from the University of Adelaide, followed by a PhD in Mechanical Engineering in 1978. In 1993, Dr Thomas was assigned as a mission specialist by NASA after an extensive one-year training. He completed four flights and has logged over 177 days in space during his 22 years of service at NASA. In his last journey on the STS-114 Discovery, he was involved in the assembly of the International Space Station, where he inspected the new flight safety procedure and repaired the thermal protection system.

Picture credit: NASA

AUSSIE WORD OF THE DAY

'BARBIE'

Short for 'barbecue', here's a term you'll hear around summertime as we Aussies love a good barbecue on a hot day.

E.g. We had friends over on the weekend for a bit of a barbie.

WEATHER

Partly cloudy

High 17° Low 11°

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ACKNOWLEDGEMENT OF COUNTRY

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A TASTE OF ADELAIDE

After a long night of deliberation over the APhO 2019 theoretical examination questions, Team Leaders and Observers were treated to a gastronomical experience that took them across the continents, from right here in the heart of Adelaide city.

From Chilean empanadas and German mettwurst, to sweet Turkish delights and savoury South Korean pancakes, the touring group indulged in some of the best delicacies one could find in the iconic Adelaide Central Market.

“I really enjoyed it. It made me feel like a local. I’ve had a taste of the life here, the local shops and its delicious food. It’s kind of rejuvenating after last night,” said China’s Team Leader Jiang Shuo.

Apart from the food, the group was also introduced to the rich history and culture behind the market, which celebrated 150 years of establishment last year. Many patrons are migrants from all over the world whose humble beginnings date back decades, creating a diverse atmosphere.

With fresh produce available in abundance, specially sourced locally and sold, food operators themselves have easy access to fresh ingredients.

“It’s nice to see so much fresh produce in one place. Coming from the United Arab Emirates (UAE), I see more modern kinds of markets where there aren’t more fresh foods in one place so it’s very refreshing. It is also great to know a lot of them are small business owners,” said Subramaniam Krishnamoorthy, UAE Team Leader.

ADELAIDE INSIDER

Brought to you by The University of Adelaide

TODAY'S SNEAK PEEK

SAPPHIRE CLOCK

Sapphire Clock

Accurate frequency and timing signals are used in most electronic systems we use every day, including radar and GPS for navigation.

The Sapphire Clock, is the result of more than two decades of research and is 1,000 times more precise than any other commercial system; it is so precise it gains or loses only one second over 40 million years.

Developed by the University of Adelaide’s Institute for Photonics and Advanced Sensing, and start-up company Cryoclock Pty Ltd, the Sapphire Clock generates an incredibly pure ultra-low noise signal.

The Sapphire Clock offers the potential for an upgrade of the Jindalee Over-The-Horizon Radar Network (JORN) system, which monitors aircraft and ships off Australia’s northern approaches.

If JORN has access to better signals then it will be able to see smaller objects, travelling slower, at much greater distances – and that means keeping Australia safer.

This is a perfect example of fundamental research in universities leading to high technology advances that benefit our nation. Be sure to keep an eye out on it when visiting the campus today!

Asian Physics Olympiad

Adelaide, Australia | 5–13 May 2019

GRAVITAS

APhO 2019 NEWSLETTER
ADELAIDE, AUSTRALIA
VOL. 4 9 MAY 2019

Gravitas was inspired by the Latin word for 'Gravity', it being the fundamental force of nature that holds our universe together - much like the passion for physics that binds people of diverse backgrounds and aspirations at a momentous occasion like APhO.

KOALA-TY TIME

Printed by Toshiba

INSIDE

UP-CLOSE WITH OZ'S LOVEABLE MARSUPIALS

Visiting South Australia's wildlife sanctuary home

ON-CAMPUS TOUR

Insight into cutting-edge facilities

EXPERIMENTAL EXAM

Working around the clock for the final exam

UNIVERSITY EXPERIENCE

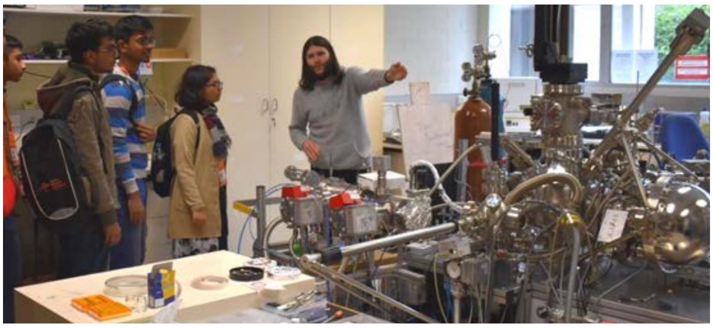
A GLIMPSE INTO THE FUTURE

After a memorable Australian wildlife encounter, APhO students had a peek into Australian university life at Flinders University.

Following a warm welcome from the university's Vice President and Executive Dean Professor Alistair Rendell, the students heard from Associate Professor Sarah Harmer-Bassell who spoke about *'What it's like to be a Physicist in 2019'.*

She used the example of mineral mining, an industry taking up 5% of total electricity costs, to demonstrate how cross-discipline collaborations can help solve global challenges. Recent PhD graduate Dr Yanting Yin also gave the students some insider's guides about studying abroad and his experiences as an international student himself.

The university visit wrapped up with an eye-opening physics lab tour, exposing APhO students to some of the most cutting-edge facilities in the College of Science and Engineering.



Researchers from Flinders University also explained the features of several unique techniques involved in ongoing research, including the Metastable Induced Electron Spectroscopy (MIES), which can determine the molecular structure of the outermost layer of a sample by measuring energy spectrums.

DIYAR TULENOV
Kazakhstan

"I found the speech from Professor Rendell the most interesting. I got to know who Flinders was and how the university was founded. I also got to learn more about the history of the UK and Australia. I feel like the university life in Flinders must be very fascinating and motivating."

NIYATI MANISHKUMAR MEHTA
India

"The lab facilities are quite different from what I've seen in our country. It's an eye-opening experience to me as I haven't carried out many experiments in my school yet. I'd love to pursue a research career in physics or related fields in the future."

SHEIKH SHAFAYAT
Bangladesh

"I found Dr Yin's speech inspiring because he followed his curiosity and eagerness to learn new things. He found out the knowledge gap when he worked in the solar panel company, then he decided to fill the gap by doing a PhD."

INNER-WORKINGS OF A PAPER TRANSLATION

Associate Professor Vyacheslavs Kashcheyevs

While students were out enjoying a nature-filled day, Team Leaders were involved in the second round of translation of the final examination papers. "The purpose of the paper translation is to take away any language comprehension efforts without adding any hints so that the only thing left for students to solve is physics," one of the Head Markers, Associate Professor Vyacheslavs Kashcheyevs shared.

This expert in quantum physics is part of the International Academic Committee of European Physics Olympiads. He has since been involved in the International Physics Olympiads (IPhO) for over a decade. His connection with physics Olympiads dates back to 1996 when he won a bronze medal in the 27th IPhO in Norway. "It's a privilege to be able to use my expertise to help the young generation of physics students discovering their talent," the Physics Olympiad medalist said.

The team leaders had been through a challenging time discussing the experimental paper, "They dived into the problems to develop a full understanding of exactly what's going on and what their students are supposed to do," Associate Professor Kashcheyevs said. He appreciated the essential role Team Leaders played in helping students to perform at their maximum capacity, saying, "Their expertise in physics enables the translation to be as comprehensive and concise as possible, to the extent that any non-English speakers wouldn't come across any language barriers."

COSYING UP TO AUSTRALIA'S WILDLIFE

APhO students continued their exploration of Australia's native land yesterday with a more than exciting trip to the Cleland Wildlife Park.

Some being unsure of what was in store for them, it did not matter that the unpredictable weather brought cloudy skies and a breeze of 16°C through the serene atmosphere, which buzzed with thrilled teenagers all at the same time.

The Park is home to many native Australian wildlife, these including the kangaroo, koala, emu, wombat, dingo, Tasmanian devil and several bird species. It was clear that the favourites of the lot were the ever-curious kangaroos and cuddly koalas as students spared no time in getting within inches of these lovable marsupials.

“It was the first time I came in contact with these animals and it was a great experience feeding the koalas and kangaroos,” said Rawan Alghamdi, student from Saudi Arabia who did not shy away from petting the curious grey kangaroos. “It was also a great choice bringing us here after the exams so we can change our moods and get ready for tomorrow's exam,” she added.

For Russia's Irina Lialikova, it was also a pleasant change of pace from the challenging days before. “We have some places like this in Russia, but we have different animals, nature and landscapes, so it has been wonderful for me. I just adore the nature.”

The animals were equally eager to cosy-up to students, strutting their waddles or hopping about getting close to students.

“This is great because you can directly interact with them. At the zoos back in my country you cannot touch the animals, they are in cages. We really like the environment here and it was relaxing, with fresh air, it's really nice,” said Turkish student Mert Unsal.

To Dhruv Kumar Gupta of India, his first time in Australia was complemented by the opportunity to wander the park alongside the animals.

“I'm seeing the emus, kangaroos and wallabies for the first time and it's really amazing. When we heard we were going to Cleland Wildlife Park, I was really excited because I knew we could do these exciting things.”






AUSSIE WORD OF THE DAY

'FAIR DINKUM'

Slang for ‘fair’ or ‘true’, this phrase is often used to proclaim a confirmation.

E.g. “That’s fair dinkum!”

WEATHER

Rainfall

High 15° Low 15°

Don't leave without your umbrella!

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HAPPY BIRTHDAY!

SIOBHAN TOBIN

Team Leader, Australia

AUSTRALIA'S PHYSICS TRAILBLAZERS

Professor Brian P. Schmidt is an American-born Australian astronomer who shares the 2011 Nobel Prize in Physics with Saul Perlmutter and Adam Riess. They discovered that the expansion of the Universe is accelerating by observing exploding stars, called supernovae. He said the Universe is expanding in a way that galaxies and stars are moving away from one and another. The scientists could also estimate how fast the Universe spreads out by measuring the movement of the light emitted by supernovae.

ADELAIDE INSIDER

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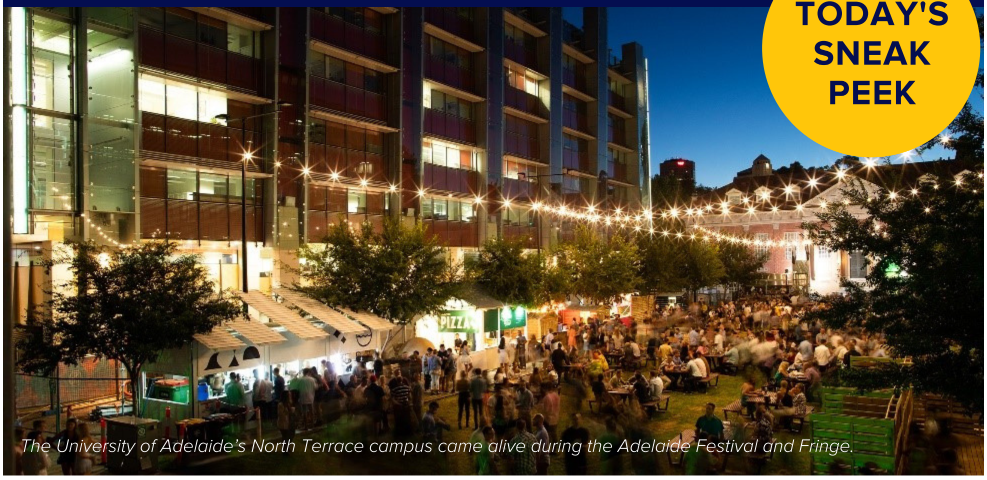
TODAY'S SNEAK PEEK



The University of Adelaide’s North Terrace campus came alive during the Adelaide Festival and Fringe.

ADELAIDE, THE FESTIVAL CITY

We hope you are enjoying your time here in Adelaide. You might be interested to know that Adelaide has been recognised as one of the best festival cities in the world and regularly hosts world-famous events and festivals that showcase our exceptional food, wine, sport, art and vibrant city life.

You’ve probably already noticed that Adelaide is a walk-able city. Getting around is easy. Being a smaller city, you can feel the festivities in the air whatever part of town you are in. Our events really do take over the city.

During February and March, the University of Adelaide opened our main campus to over 220,000 new visitors as we became the beating heart of one of the world’s most popular cultural events; The Adelaide Festival and Fringe. We proudly played host to performers from all over the world, and people of all ages enjoyed the lively atmosphere at the University’s historical and iconic grounds.

The University’s North Terrace campus is a vibrant hub within the city centre for students, a destination for everyone, including school children, cultural connoisseurs, tourists, business leaders, athletes, future students and more, as well as our staff, their families

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SCORING GOALS ON AND OFF THE FIELD

Printed by Toshiba

INSIDE

KICKING BACK

Game day after the final exam

REUNION DINNER

A multicultural fun night out

EXAM MARKING PROGRESS

Few days away from finalising results

APhO 2019 SO FAR...

YUWANZA RAMADHAN

Indonesia

"I found the style of the experimental exam to be quite different from what we've trained for, which makes it challenging. Our training focused on calculation skills, but the difficult part of this exam was comprehending the concepts. Once I understood the idea, the calculations and graph were quite straightforward for me."

XIAORUI ZHANG

Singapore

"I found the first question involving magnetic properties and optics quite challenging. The second question was about investigating the movement of the ferrofluid with and without the effect of magnets. But in general, I felt the experiment was slightly easier than the theoretical exam."

ALEXANDER LIN

Australia

"I think ferrofluid is a deep concept for almost everybody, but it was explained very clearly. I also found it interesting to see the effects, like the peaks that formed when you put magnets nearby."

FRANKLIN HOR CHUNG YEUNG

Macau

"I love the environment and fresh air in Adelaide and the city feels quite different from my hometown. I am so glad I've met so many brilliant friends from different countries here and our own team has bonded much tighter than ever before."

ANDREI PANFEROV

Russia

"The best part of APhO 2019 for me is the exams. That's firstly what APhO is about. I really enjoy challenging myself and solving physics problems. In the future, I'd like to study Theoretical and Advanced Physics at one of the best universities back home."

CHIH-CHEN LIU

Taiwan

"I am looking forward to the upcoming cultural experience and making more new friends. We've been playing card games with teams from Macau and Malaysia. Though we're not very familiar with each other yet, I'd love to know more about them."

MARKING STARTS IN FULL FORCE

Congratulations to all of our young physicists who have successfully completed the challenging APhO exams. While you continue discovering Adelaide, your exam papers have now been delivered to the marking team. One of the Head Markers, Dr Bonnie Zhang, who herself is a former Physics Olympian explained the next steps.

"We have about 30 markers for the theoretical and 20 for the experimental exams. A number of them are PhD students from leading universities from all over Australia. We have a few academics on the team as well," Dr Zhang said.

The marking of the experimental exam is expected to finish by Thursday evening. "Team Leaders will then get to mark their own team's papers again and any further discussion will take place on the moderation day," she added.

"Having almost 170 students with their 5 hours' worth of work, our priority is being consistent and fair, and our Markers have been taking a lot of care and putting dedication into that work," Dr Zhang concluded.

ARVO AT THE OVAL

The APhO 2019 has seen some of the world's brightest minds and after yesterday, it was clear that some of these talents could even imagine a future as a professional footy player.

Following the 5-hour experimental exams today and a huge sigh of relief to mark the overall end of the APhO examinations, students headed over to the magnificent Adelaide Oval yesterday afternoon to learn first-hand the techniques behind Australia’s favourite sport, Australian Football, popularly known as ‘footy’.

In addition to learning the techniques involved in throwing and kicking the egg-shaped football, the students were also treated to a friendly match of tennis with one another, which certainly seemed like a great way to spend their downtime.

Standing tall as Adelaide’s pride for 148 years now, the Adelaide Oval has seen 16 sports played on its grounds including cricket, baseball, gridiron, hockey, tennis, archery, lacrosse and the popular footy, which begins its season come winter every year.

Besides the fun-filled sporting experience, students were taken on a tour of the Oval, being introduced to the history of the coveted stadium and some of the best cricket and footy players. Interestingly, the Oval has hosted several prominent artists, among them are Madonna, Michael Jackson, Elton John, David Bowie and Paul McCartney.

A NIGHT OF CULTURAL CELEBRATION

Delegates from 22 countries gathered in a star-studded celebration at the Reunion Dinner, having completed the two 5-hour exams. Check out some of the best highlights from last night.

AUSSIE WORD OF THE DAY

'ARVO'

Short for 'afternoon', this is one word you will hear almost every day.

E.g. What time shall we meet this arvo for lunch?

WEATHER

Shower or two

High 15° Low 8°

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ADELAIDE INSIDER

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TODAY'S SNEAK PEEK

City living in Adelaide

UNI LIFE IN THE HEART OF THE CITY

Adelaide is the safest, cleanest, greenest and most affordable Australian city in which to study. The city has a population of around 1.3 million people who lead a relaxed but vibrant lifestyle.

The University of Adelaide's city campuses are located in the heart of the central business district; within walking distance of major cultural and sporting attractions and next-door to emerging technology precincts – the Australian Space Agency, Biomed City (health) and Lot Fourteen (a hub for innovation).

The University offers managed student accommodation, the largest of which is The University of Adelaide Village. Situated in Adelaide's central business district in the dynamic Central Market and Chinatown precinct, The Village offers students a well-balanced University lifestyle.

The chance to live and study in the city opens up endless possibilities to mix study time with time out.

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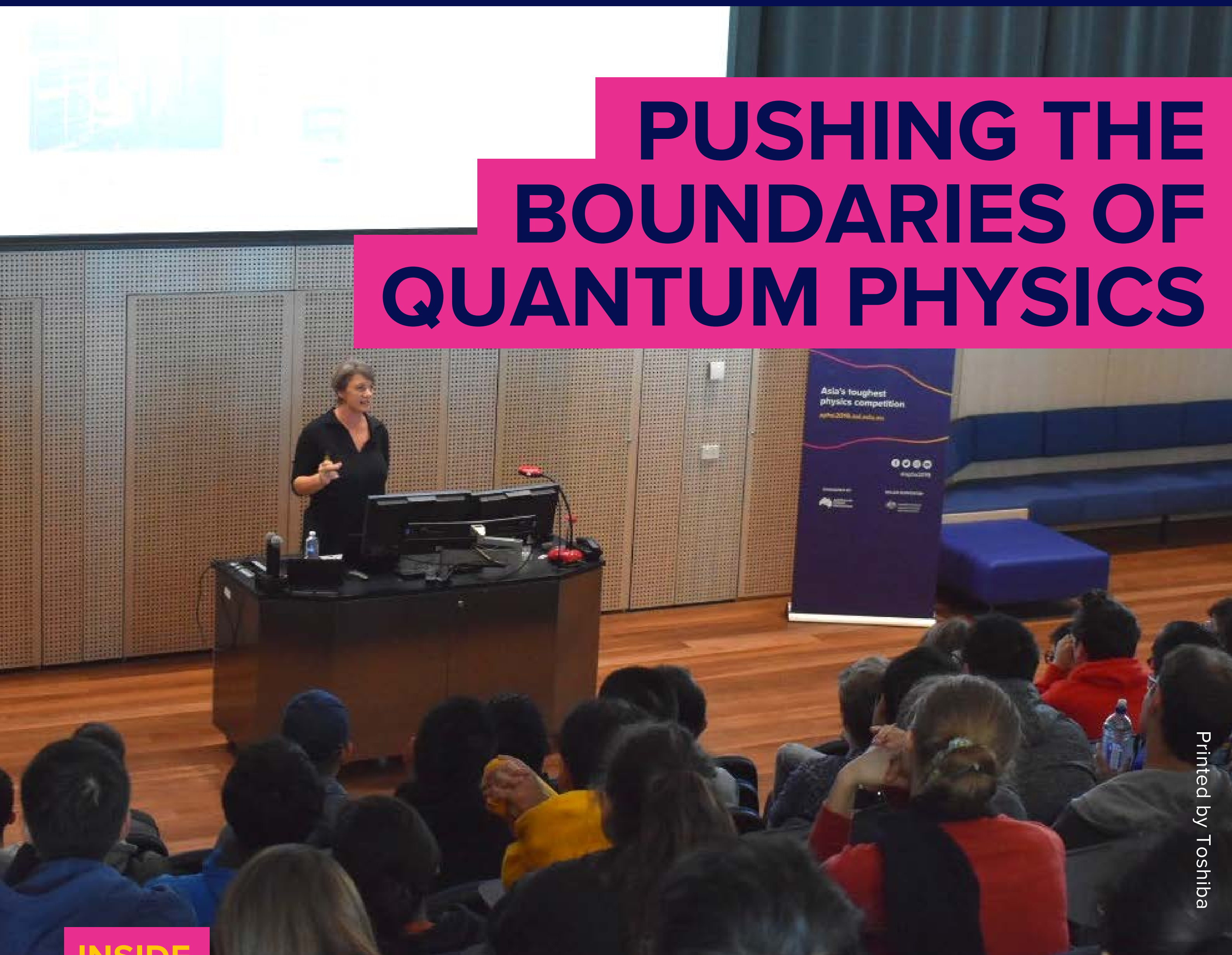
PUSHING THE BOUNDARIES OF QUANTUM PHYSICS



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INSIDE

APhO ADDRESS
Royal Society Fellow and 2018 Australian of the Year delivers inspiring address

REAL-WORLD CHALLENGE
Finding a carbon neutral heating solution

LOOKING SKYWARD
Observing the galaxy of stars in the Australian night sky

FORGING AHEAD WITH QUANTUM COMPUTING

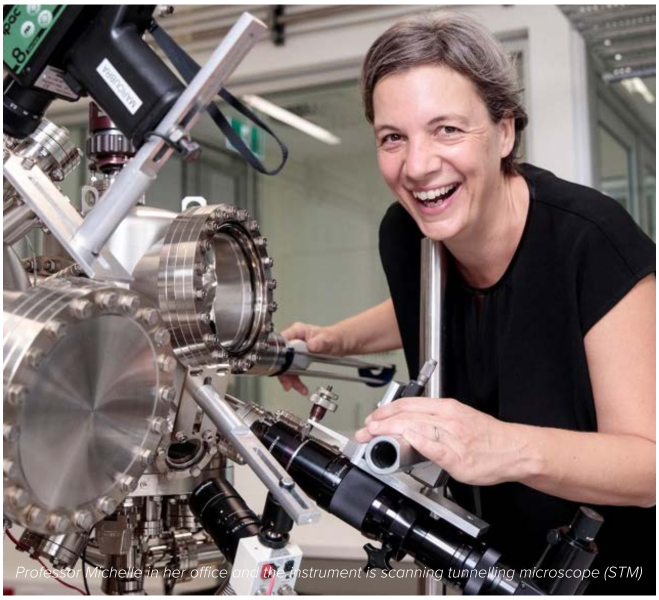
It isn't every day you get to hear from an Australian of the Year. When that person also happens to be an esteemed member of the physics fraternity, it truly makes a highlight in this APhO experience.

Yesterday, APhO delegates had the unforgettable opportunity to hear from Professor Michelle Simmons at the APhO address. A Professor of Quantum Physics at the University of New South Wales, Michelle shared how quantum computing could change the world. One of those ways was using the field in precision forecasting to reduce weather related deaths.

"People often talk about modelling physical systems. For example, as far as the weather goes, it's a very complex system of a lot of variables. If you can have a computer that looks at all those calculations in parallel, then those precisions can help predict the weather."

Other life-changing areas that could see improvements with the use of quantum computing include cancer detection, the development of superior drug-based treatments and the discovery of Earth-like planets using data collected by telescopes. The session ended with a Q&A where students took the golden opportunity to ask some questions from the quantum computing expert.

Q&A WITH PROFESSOR MICHELLE SIMMONS



Professor Michelle in her office and the instrument is scanning tunnelling microscope (STM)

What is the best advice somebody has given to you?

From my father to me: Do what's easy for a hobby and what's hard for your everyday job – that way you will always be challenged.

What is your favourite part of the job?

Creating things that have never existed before. Interacting with students and postdocs in my lab, reading papers, pushing the boundaries of what is known and creating new tools, devices and mathematical models.

What do you think are the emerging physics trends to watch?

The application of machine learning to quantum control, new methods in statistical physics and new experimental technologies that allow us to control the world at the quantum limit.

Thoughts about closing the gender gap in STEM?

We have to be patient – it is happening. The most important thing is that women don't miss out on the exciting jobs out there in the mathematics, physics and computing space.

If you're not in the lab, where else would we find you?

In the library reading papers.

Any message to our Physics Olympians?

You live in a great place in the world. You are working in one of the most rewarding fields. Be ambitious and bold and see where pushing the boundaries of your knowledge takes you!

YUNUS EMRE PARMAKSIZ
Turkey

"Professor Michelle not only clearly explained many technical terms and algorithms but also covered many unique aspects that are not commonly seen in other quantum computing seminars. The content was very comprehensive that I basically understood everything she explained. I got very excited when she mentioned the Shor's algorithm, which is a topic I am quite familiar with. The algorithm is about finding a prime factor of a certain amount of digital numbers. Without it, you can easily decode encryptions in any banking systems. I also asked her a question about how to differ indistinguishable particles and I received an illuminating answer. I've been thinking about pursuing my studies in quantum computing because of my passion for computing, physics and mathematics. Her talk has absolutely encouraged me to advance my knowledge of quantum physics and follow my dream."

CONNECTING BEYOND CLASSROOM WALLS

It was a test of more than physics know-how when students were put to work yesterday in trying to revive one of Adelaide's iconic buildings, the Bicentennial Conservatory.

Standing tall at 27 metres in the Botanic Garden, the structure was once home to many tropical plant species. However, those species are on a decline as high costs and carbon emissions resulted in the enclosure's heating being switched off.

Keeping those factors in mind, it was up to these 170 brilliant young students to come up with a new heating solution to maintain tropical conditions together with the help of new peers from the Adelaide Botanic High School, which facilitated the Team Field Investigation exercise.

The investigative excursion students split from their country teams and spread into new teams before they were set off on an investigation of the conservatory's function before suggesting innovative solutions.

Assistant Principal of Adelaide Botanic High School Brontë Nicholls said the exercise was an idea in the works for the last 12 months.

“Having some of the best physics minds in the planet putting their ideas into it, whatever possibly comes out of it could be useful. They had some interesting ideas,” she shared.

Indeed, some of the ideas the teams came up with included the possibility of using biofuel, solar panels or insulated glass panels to facilitate the heating. Thinking deeper, some teams also presented potential downsides to these ideas. Brontë said that the exercise was more than just about finding potential solutions.

“It's understandable when this type of activity hasn't been done before and probably hasn't been part of what people would associate with the Asian Physics Olympiad. But this has enabled international collaboration and the building of strong relationships across cultures that you don't get through the individual examinations,” added Brontë.

WHY QUANTUM PHYSICS MATTERS?

Quantum physics that emphasises energy interactions at the atomic or subatomic level, has brought significant impacts going well beyond the ultra-tiny world and into our everyday life. For example, the production of all your favourite electronic gadgets relies on the application of quantum physics. By manipulating the electron movement in solid objects, we can create semiconductors with different electronic properties that are essential for fabricating computer chips.

But humans aren't the only ones using the mysterious physics. Scientists have suggested that some birds can navigate via sensing subatomic events happening in their eyes. A light-activated protein in the birds' retina contains a pair of free electrons that can be stimulated by sunlight. Upon the activation, the electron pair becomes ‘tangled’ and susceptible to the surrounding Earth's magnetic field, informing the bird which direction is the north as a result.

BENEATH THE AUSTRALIAN SKIES

A trip to Australia wouldn't be complete without a stargazing experience as the country is known for having low-light pollution. In a must-visit tour to the Stockport Observatory, students were greeted by astronomers from the Astronomical Society of South Australia. The astronomers pointed out constellations to the students, including the famous Southern Cross. Students also seized the opportunity to see the Moon and its craters, magnified up to 240 times using the resident telescopes.

AUSSIE WORD OF THE DAY

'ROO'

It is an Aussie way to call a kangaroo.

E.g. "The baby roo is still in its mom's pouch."

WEATHER

Possible shower

High 18° Low 10°

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ADELAIDE INSIDER

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TODAY'S SNEAK PEEK

The white sands and blue seas of Adelaide beaches

A TRAM RIDE AWAY TO THE BEACH

Another great thing about Adelaide is our proximity to the white sandy beaches that Australia is famous for.

You can hop on a tram out the front of the University of Adelaide, and 25 minutes later you will find yourself at Glenelg Beach, Adelaide's most popular city beach.

It's a great place to relax and immerse yourself in Australian culture. Renowned for its wide beach, stunning sunsets, rich heritage, charming hotels and bustling shops, sidewalk cafés and loads of entertainment; there's no shortage of fun to be had.

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MAKING WAVES AT GLENELG

Printed by Toshiba

INSIDE

SEAS THE DAY

Beach safety tips with Adelaide's finest

MODERATION DAY

A step closer to finalising exam results

AUTOGRAPH PAGE

Leave personalised and heartfelt message to your mates

GLENELG GETAWAY

Every time you see red and yellow flags up, you know Glenelg lifesavers are patrolling along the coastline to keep beachgoers safe. “I didn’t know much about life saving before, but now I realise their job is vital. I’ve definitely learnt a lot about how they rescue people,” said Sze-Chun Lau from Hong Kong.

Yesterday morning, APhO students extended their cultural explorations to the Glenelg Surf Life Saving Club, a lifesaving organisation of South Australia established in 1931. Friendly volunteer lifesavers organised an ergo rowing competition for students to warm up and have a taste of what it’s like to row an inflatable rescue boat.

All the young physicists enthusiastically participated, with Australia's Simon Yung winning first place.

Following the friendly competition, students took a peaceful stroll along the beautiful beach when they were pleasantly surprised by several spotted seals swimming under the Glenelg jetty.

“I was very excited when I saw the seal. It’s a huge fellow. I also love this white sandy beach as it’s quite different from beaches in my hometown,” said Puth Srey Neath Pich from Cambodia.

For Saudi Arabian Moaaz Fayumy, the cool weather is something he enjoys. “I really like it here. Summer in Saudi Arabia is always very hot. Glenelg has a breathtaking ocean view and I enjoy watching the waves coming towards me with the breeze. I really wish we could have more time for outdoor activities like this and explore more about Australia's nature and wildlife,” he said.

SZE-CHUN LAU

PUTH SREY NEATH PICH

MOAAZ FAYUMY

ESSA ALFAIFI

SAUDI ARABIA

“It’s been a great experience, especially since the organisers did such an amazing job. To me, organising those visits with the entire group was also nice. This will truly be a memorable experience."

FABIOLA LIP

SINGAPORE

“The Australians are very hospitable and despite the cool weather you just feel warmth everywhere. They go out of the way to make us feel very welcome. I have been involved in the Olympiads for the last 18 years and always looked forward to Australia hosting the Olympiads. It’s finally here now.”

SUMATHIPALA HALPITA

SRI LANKA

"It's been wonderful here. We had a beautiful experience at Cleland Wildlife Park with the kangaroos and koalas. It was my first time seeing them and they were just fascinating. We also visited the city and did a bit of shopping so overall it has been a great experience."

SPREAD THE WORD

Friends and family worldwide can now join us for the Closing Ceremony on 12 May to find out who will be going home with the coveted medals. Tune in on our Facebook page live at 3.30pm (GMT +9.30).

AUSSIE WORD OF THE DAY

'STRAYA'
Short for 'Australia'.

E.g. Hope your stay in Straya has been great!

WEATHER

Possible shower

High 17° Low 9°

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MODERATION DAY

The last and final leg of the APhO 2019 examination process took place yesterday as Team Leaders and Observers spent the afternoon deliberating exam results with the Marking team.

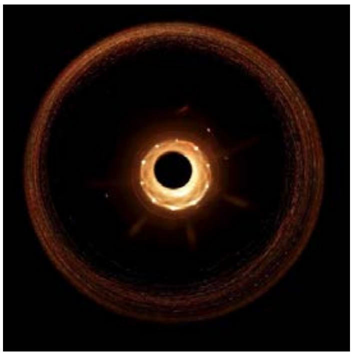
This part of the process enables Markers and Team Leaders to discuss the marks given to each student and come to an agreement over the points given for each answer. The session ended in the evening, with the final rankings discussed at the International Board Meeting.

ADELAIDE INSIDER

Brought to you by The University of Adelaide

TODAY'S SNEAK PEEK

REVOLUTIONARY NEW AREA OF ASTRONOMY & ASTROPHYSICS



Gravitational wave astronomy is a revolutionary new area of astronomy and astrophysics. Gravitational waves provide information about the evolution of the universe which was previously not available through electromagnetic radiation or particle-based observations.

Gravitational waves provide a new way of sensing the universe and observing its early history.

The University of Adelaide's gravitational wave research group was an active contributor to the first successful detection of gravitational waves in 2015, and was awarded the 2017 Nobel Prize for Physics.

This detection observed stellar mass black hole binaries for the first time and provided the most extreme tests of Einstein's Theory of General Relativity. In 2017 the collision of two neutron stars was observed for the first time and the resulting wave-forms gave insight into the structure of the most extreme nuclear matter in the universe.

The group is currently developing new systems with advanced optical diagnostics. These systems will enable the laser beams used in the LIGO and Virgo detectors to be constantly monitored and adjusted during use, which will significantly increase detection rates and fidelity.

The next step will be a range of next-generation detectors. The group is also exploring technology that will use silicon mirrors cooled to about minus 150°C. This may allow detectors to routinely observe gravitational waves from coalescing black holes and neutron stars, and search the universe for previously undetectable new sources.

Autographs + Messages

UNTIL WE MEET AGAIN

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APhO 2019 NEWSLETTER
ADELAIDE, AUSTRALIA
VOL. 8 13 MAY 2019

Gravitas was inspired by the Latin word for 'Gravity', it being the fundamental force of nature that holds our universe together - much like the passion for physics that binds people of diverse backgrounds and aspirations at a momentous occasion like APhO.

RAISING THE BAR

Printed by Toshiba

INSIDE

STELLAR RESULTS

Top performing students bring home coveted medals

CLOSING CEREMONY HIGHLIGHTS

Excitement builds up at awards ceremony

SEE YOU IN 2020

The next APhO host city revealed



CLOSING CEREMONY HIGHLIGHTS

THE APhO 2019 COMPETITION MAY BE OVER, BUT IT SHALL NOT BE FORGOTTEN

Over the past week, all eyes were on Adelaide as Asia's top physics students came together in a merging of knowledge, cultures and creation of new friendships. This took place at the much talked about Asian Physics Olympiad 2019 that finally came to an end last night after the competition winners were crowned.

Throughout the week, it had been clear that the competition was more than an event that put physics knowledge to the test. Students spent time getting to know one another and working field investigations together, in turn sharing knowledge and creating lasting memories.

“You being here demonstrates your abilities, and commitment to learning and challenging yourself with healthy competition, which sets you up for the future. By coming here to connect with others and to build a collaborative skill that are essential for all modern occupations, you are setting yourselves on excellent paths.

"The contacts you take away from here are every bit as important as the academic learning you’ve done to get here,” said Dr Matthew Verdon, Chair of APhO Academic Committee in his address at the ceremony.

This year’s competition saw 9 gold, 16 silver and 33 bronze medalists. The ceremony was streamed live on Facebook, which engaged viewers from all over the world.

Before the ceremony concluded, the host city of the next APhO was announced and a short video presentation was delivered by the Taiwanese organiser.

The ceremonious affair ended beautifully with a captivating performance of Kaurna and Narungga man Jack Buckskin and the Kuma Kaaru dancers who bid farewell to the delegates through a special indigenous dance.



SPECIAL PRIZE WINNERS

OVERALL WINNER
GRIGORII BOBKOV, RUSSIA

THEORETICAL WINNER
RUOYU YAN, CHINA

EXPERIMENTAL WINNER
RASSUL MAGAUIN, KAZAKHSTAN

BEST FEMALE PERFORMER
SHU GE, SINGAPORE

BEST AUSTRALIAN PERFORMER
STEPHEN CATSAMAS

PRESIDENT'S AWARDS WINNERS

BEST MALE PERFORMER
GRIGORII BOBKOV, RUSSIA

BEST FEMALE PERFORMER
SHU GE, SINGAPORE

MOST CREATIVE THEORETICAL SOLUTION
GRIGORII BOBKOV, RUSSIA

MOST CREATIVE EXPERIMENTAL SOLUTION
CHUN-WANG CHAU, HONG KONG

MOST DESERVING MALE
SIMON YUNG, AUSTRALIA

MOST DESERVING FEMALE
ROSEMARY ZIELINSKI

AUSSIE WORD OF THE DAY

'HOOROO'

Commonly used in Australia to say 'goodbye'.

E.g. "Hooroo, see ya real soon!"

WEATHER

Partly cloudy

High 19° Low 11°

Stay warm and wishing you all a safe flight home.

JOIN THE CONVERSATION

@apho2019

apho2019.asi.edu.au

ACKNOWLEDGEMENT OF COUNTRY

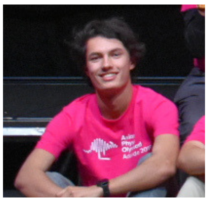
Kaurna miyurna, Kaurna yarta, ngadlu tampinthi

The Asian Physics Olympiad Committee acknowledges that we are meeting on the traditional country of the Kaurna people of the Adelaide Plains. We recognise and respect their cultural heritage, beliefs and relationship with the land. We acknowledge that they are of continuing importance to the Kaurna people living today.

MESSAGES FROM OUR TEAM GUIDES

"I just want to thank all the teams for coming and being such lovely students. I hope they had the best week and I know they're going to do amazingly in the future."

NISHKA TAPASWI
India



"Cambodia is such a fun team to get to know. We discussed all sorts of subject matters. I wish them all the best in the future and I also really want the team of United Arab Emirates to know that they should be very proud of what they were able to do in such a short time. I'd like to thank them for how well they participated in all the events."

ALISTAIR DE VROET
Cambodia & UAE

"Sometimes you get very concerned about the results and the competition, but you don't have to. The most important thing is that you helped each other as a team and now you've all become better. The achievement you've made at your age is outstanding. I hope all students enjoyed APhO 2019 and will positively impact the society in the future."

DIAN DINI PRIMADANI
Singapore

ADELAIDE INSIDER

Brought to you by The University of Adelaide

IT'S A WRAP!

University of Adelaide North Terrace campus

CONGRATULATIONS ON COMPLETING APhO 2019

Adelaide has been proud to host you and watch on as you have challenged yourselves, stretched your intellectual capability and connected with people from all over the world.

We hope you have enjoyed your stay in Adelaide and come back to visit—or even join us at the University of Adelaide on our quest to push the boundaries of understanding and discovery in physics.

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WANT TO STAY IN TOUCH?

GALLERY


Asian Physics Olympiad Adelaide 2019
VIETNAM


Instagram
apho2019
Adelaide, Australia
I NEED HELP
E=MC²
CAUTION
EXPERIMENTS IN PROCESS!


I NEED HELP
EXTRA PAPER PLEASE!

Asian Physics Olympiad

Adelaide, Australia | 5–13 May 2019

IMPACT SNAPSHOT

22 COUNTRIES AND REGIONS PARTICIPATED

9 DAYS OF EVENTS IN ADELAIDE

168 STUDENTS SAT 5-HOUR THEORETICAL AND EXPERIMENTAL EXAMS

ECONOMIC IMPACT

41 LOCAL BUSINESSES INVOLVED

CONTRIBUTED TO **LOCAL ECONOMY** **$2.7 MILLION**

*Adelaide Convention Bureau

109 VOLUNTEERS FROM ALL OVER THE COUNTRY

4,458 VOLUNTEER HOURS = VALUE OF **$632,000**

1 IN 2 DELEGATES CHANGED THEIR LIKELIHOOD OF FUTHER STUDY IN AUSTRALIA AFTER THE EVENT

98% INTERNATIONAL DELEGATES AGREE IT WAS A GREAT EVENT

THE BEST THING WAS...

"The people, specifically the volunteers and team guides. They not only helped us with the scheduled activities, but also play a huge role in the spirit perspective."

"We were able to make new friends from across the Asia-Pacific region who shared a similar interest in physics."

"The novelty of the problems in the theoretical exam."

SOCIAL MEDIA

TOTAL ENGAGEMENTS

72,000 REACH

61,992 IMPRESSIONS

58 RETWEETS

1,439 LIKES

2,235 VIEWS

CLOSING CEREMONY FACEBOOK LIVE STREAM

5,303 REACH **49** SHARES

2 min AVG WATCH TIME

#APHO2019

AWARDS

9 GOLD

16 SILVER

33 BRONZE

29 HONOURABLE MENTIONS

13 SPECIAL PRIZES

TOP EXPERIENCES

SPECIAL ADDRESS BY PROFESSOR MICHELLE SIMMONS

VISITS TO LOCAL SCHOOLS AND UNIVERSITIES

SUPPORTERS

ORGANISED BY

AUSTRALIAN SCIENCE INNOVATIONS

MAJOR SUPPORTER

Australian Government
Department of Industry, Innovation and Science

*ASIAN PHYSICS OLYMPIAD 2019 INTERNAL SURVEY

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