自主探索實驗物理(self-exploratory experimental physics)

本課程可抵免下列必修課 This course can replace the following required courses.

1. 基礎物理實驗 Fundamentals of Experimental Physics (202 33100)
2. 近代物理實驗 Modern Physics Lab (202 36200)

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課程資料網站（Web site for course materials）

http://idv.sinica.edu.tw/jwang/seep

課程概述 (Introduction)

傳統的實驗課程以現成的儀器設備讓學生操作，雖然名為實驗，但是由於實驗的方法和器材已經固定，學生自主探索的自由度很低，與實驗所應講求的探索精神脫節。另一方面，傳統的實驗課程重視操作的訓練，卻未能培養學生建造儀器、設計實驗、團隊合作、經營專案的能力，而這種能力是實驗物理的精髓，也是在科學上開創新局的資本。針對解決上述這兩個問題，本課程將帶領學生以自主探索的方式學習實驗物理，培養學生運用現代光機電技術的能力，強調動手建造、創新設計，建立學生解決技術問題的自信。學生經由文獻查考、計畫提案、實驗設計、儀器建造、進度和預算控制、數據分析、成果報告、公開展覽這一串環環相扣的流程，每個階段都得到助教的協助和老師的講評，可獲得密集的技術訓練和完整的企畫、執行經驗。由於這個過程沒有固定的道路可依循，學生將體會自主學習、時間管理、團隊經營、決策風險的挑戰，這也是領袖級科技人才應有的訓練。有鑑於學生對於現代光學、電子、機械、計算機的運用能力缺乏訓練，上學期的課程以訓練學生的製作科學儀器的能力為目標，下學期則應用現代的光機電技術，輔以計算機的訊號處理和分析，以自製儀器重現古代經典實驗，驗證物理定律或測量重要的物理常數，並達到同等級的精確度。

In traditional experimental courses students play with ready-made instruments to observe physics phenomena. Although it is called an experiment, students' freedom of exploration has been limited by fixed setups, and therefore is disconnected to the spirit of exploration that an experiment asks for. Moreover, traditional experimental courses focus on operational training, but fail to cultivate students' ability to construct instruments, design experiments, build a collaborating team, and manage projects. Such ability is essential for experimental physics and also a foundation for innovation. In order to solve these two problems, this course will lead students to learn experimental physics in a self-exploratory way and cultivate students' ability to use modern electronic, optical, and mechanical techniques. It emphasizes hands-on construction and

innovative design to build students' confidence in solving technical problems. Through literature search, project proposal, experimental design, instrument construction, budget control, data analysis, progress report, open exhibition, students are assisted by teaching assistants and receive comments from the instructor at each stage to acquire intensive technical training and build a comprehensive experience in project planning and execution. Since there is no fixed path to follow in this process, students will experience the challenge of self-learning, time management, teamwork, and decision-making risk, much the same as a leader in science and technology should be prepared for. In view of students' general weakness in applying modern optical, electronic, mechanical, and computer techniques, the first semester course aims to develop students' ability to make scientific instruments or prototypes of invention. In the second semester, students are asked to use modern technologies supplemented by computer signal processing and analysis to reproduce results of classical experiments. The goal is to verify laws of physics or measure important physical constants and achieve a comparable level of precision as the pioneers in the history.

課程目標 (Objectives)

本課程之目標在於培養學生下列的能力：(1)儀器設計與製作，(2)實驗設計與執行，(3)雷射、光學、電子、計算機科技的運用，(4)數據分析與動畫呈現，(5)團隊合作、專案經營、表達與宣傳。這方面的訓練不僅對於有志於實驗物理的學生非常重要，對於想要進入高科技產業發展的學生，也是提高自己競爭力的有效途徑。

The goal of this course is to cultivate students' ability in (1) instrumentation, (2) experimental design and execution, (3) application of laser, optics, electronics, and computer technology, (4) data analysis and animation, (5) team work, project management, and presentation. Such training is not only important for students who wish to become an experimental physicist, it is also an effective way to enhance one’s competitiveness for a career in high-tech industry.

課程內容（Content）

實習部分：電子電路設計與製作、計算機程式設計、數據擷取、儀器電控、數據分析、行動裝置程式設計、無線網路應用、機械元件製作、3D 原型開發、雷射光學技術、奈米顯微術、光譜技術。

上學期專案：研究製作具有創意和實用性的光機電整合裝置，可用為教具，或達到具有申請專利的商業價值。下學期專案：利用現代電子電機光學技術重現

古代經典實驗，驗證物理定律或測量重要的物理常數，並達到同等級的精確度。

Training: design and construction of electronic apparatus, computer programming, data acquisition, automated instrumental control, data analysis, programming of mobile devices, application of wireless technology, making mechanical components, 3D-prototyping, laser and optics, nanometer microscopy, spectroscopy.

First semester project: making creative and practical optoelectronic and electromechanical devices that can be used for educational demonstration or valuable for patent application. Second semester project: utilizing modern technology to redo classical experiments, verifying physical laws or measuring important physical constants, and achieving a comparable precision as the pioneers in the history.

課程資源 (Resources)

1. 中央研究院原子與分子科學研究所機械加工學生工場，內有車床、銑床、鑽床、衝床、折床、砂輪機。Student machine shop at Institute of Atomic and Molecular Sciences, Academia Sinica, equipped with milling machine, lathe, drilling machine, bending press, stamping press, and grinder.
2. 中央研究院原子與分子科學研究所 219 室實習工場，內有雷射切割機、小型數位機械加工機、各式電子測試儀器、光學桌、光學元件、鏡架、平移台、旋轉台、各式小型雷射。Student work shop at Institute of Atomic and Molecular Sciences, Academia Sinica, equipped with laser cutter, miniature machining machine with digital control, electronic test equipment, optical table, optical components, mirror mounts, translation stages, rotation stages, small lasers.
3. 物理館 206 實驗室，內有個人工作台、個人手工具組、手持式電動工具、各式電子測試儀器、3D 列印機。Student work shop at room 206, physics department of National Taiwan University, equipped with personal work bench, hand tools, hand-held power tools, 3D printer.

教學方式（Teaching）

主要活動：(1)預習與進度報告，(2)分組專案實習，(3)成果展示，(4)老師講評與問答。

Main activity: (1) preparation and progress report, (2) group term project, (3) exhibition of accomplishment, (4) comment and question from instructor.

評量方式（Evaluation）

配分比例：考試 20%，實驗成果 50%，紀律、毅力、效率、士氣、策略、合作 15%，報告的品質 15%。

Examination 20%, accomplishment in experimental project 50%, discipline, perseverance, efficiency, morale, strategy, and team work 15%, quality of reports 15%.

評量要點(points of evaluation)：

1. 工作紀律(discipline)：報告是否按時交，工作場所是否收拾整潔，工作是否按計畫進行，工作日誌是否紀錄詳實，是否缺席。Reports submitted on time, work places tidied up after use, logbooks written with sufficient detail? Absence from class without a compelling reason?
2. 報告品質(quality of report)：內容是否具有讓他人學習的價值；表達是否清楚，論述是否嚴謹；格式是否易於閱讀且能顯示要點，是否正確引用參考資料。Content valuable for learning by others? Expressions clear? Arguments rigorous? Format easy reading with points highlighted? References cited properly?
3. 團隊合作(team work)：是否能將分內的工作做好；是否主動負責，樂於助人；是否具有領導能力。Completed one's share of work on time with good quality? Active, responsible, and helpful to others? Leadership?
4. 實驗設計(experimental design)：是否有效運用現代科技的優勢，是否能掌握實驗的精確度。Effective use of modern technology? Good control of experimental precision?
5. 經營能力(project management)：預算、執行計畫、分工是否合理，士氣是否能維繫。Budget, execution plan, distribution of work reasonable? Morale of the team?
6. 實驗成果(accomplishment)：作品的品質和使用資源的效率。Quality of work? Efficient use of resources?

提案報告、進度報告，結案報告評分準則 (Guidelines of grading for project proposal, progress report, and final report)

1. 設計與製作(design and construction)：(1)工藝的細緻度、可靠度，(2)習得技能之等次，(3)達成之規格，(4)成品之技術整合性、操作自動化、系統擴充性。(1)precision and reliability, (2)acquired knowledge and technique, (3)accomplished specifications, (4)integration of technology, operation automation, expandability.

2. 表達能力(expression and presentation)：(1)是否有錯字，(2)是否可讓人理解，(3)參考文獻是否有效、齊全，(4)思路是否前後連貫，(5)整個學期是否連貫，前後呼應。(1)Is there spelling or grammar error? (2)Readability. (3)Are the

citations proper and complete? (4)Is the logic flow smooth? (5)Connection between proposals, progress reports, and the final report.

團隊成員互評準則 (standard of mutual evaluation within a team, when applicable)

90 分以上(above 90)：才華洋溢，技術高超，不辭辛勞，讓人願意追隨的領導人物，創業時想要倚重的夥伴。Unbeatable talent, outstanding technical ability, a diligent team mate, a dependable leader one wants to follow.

80-90 分(between 80-90)：能擔當重任，能提出有用的建設性意見，人格和能力都值得信任的好隊友。Can take the burden of heavy load and give constructive opinions. Trustworthy in both personality and ability.

70-80 分(between 70-80)：能完成分內的工作，容易配合，是個好幫手。Can complete one's share of work. Easy to work with. A helpful team mate.

60-70 分(between 60-70)：表現平庸，不能替團隊加分，但也不拖累團隊。A mediocre team mate. Does not benefit the team, yet is not detrimental.

50-60 分(between 50-60)：難以溝通或消極應付，無實質貢獻。Hard to communicate, passive, contributes nothing.

50 分以下(below 50)：對於團隊有破壞性。Detrimental to the team.

計畫成敗評分準則(standard of project evaluation)

90 分以上(above 90)：達成實驗目標，且報告詳實，有說服力，有研讀的價值。Achieved the goal completely with comprehensive and convincing reports that are valuable to read.

80-90 分(between 80-90)：達成實驗目標，報告的品質尚待改進。Achieved the goal completely, but the quality of the reports needs to be improved.

70-80 分(between 70-80)：已接近達成目標，且已經找到失敗的原因，如繼續努力應可達成目標。Close to achieving the goal. Have found the reasons of failure. Should be able to achieve the goal if continue the effort.

60-70 分(between 60-70)：未達成目標，但已有部分成果可顯示往目標前進的趨勢。The goal is not achieved. Yet the outcome shows some promising trends toward the goal.

60 分以下(below 60)：未達成目標，也未獲得可信的數據，無具體成果。The goal is not achieved. No convincing progress or result.

參考書目(Reference books)

1. 電子學(electronics)：Horowitz and Hill, *The art of electronics 2nd Ed.* (Cambridge University Press 1989).
2. 實驗儀器製作(instrumentation)：Moore, Davis, and Coplan, *Building Scientific Apparatus 4th Ed.* (Cambridge Univ. Press 2009).
3. 機械加工(machining)：*The Starrett book for student machinists 16th ed*. (L. S. Starrett company 1982).
4. 計算機概論(computer)：Glenn Brookshear, *Computer Science 9th ed*. (Pearson Education 2007).
5. 科學文件製作(document preparation)：Leslie Lamport, *LaTeX user's guide and reference manual* (Addison-Wesley 1994)
6. 程式設計(programming)：Allen B. Downey, Think Java-How to Think Like a Computer Scientist 5th ed. http://www.greenteapress.com/thinkapjava/thinkapjava.pdf
7. 英文寫作(expository writing)：Daiker, Kerek, Moenberg, and Sommers, *The writer's options, 5th ed.* (Harper Collins College Publishers 1994)

參考課程錄影 (Video references)

1. 電子學(electronics)： http://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-002-circuits-and-electronics-spring-2007/ 另有汪治平教授 16 小時授課錄影(size: 32GB)，可向助教索取。
2. 機械加工(machining)：MIT TechTV machine shop video. http://techtv.mit.edu/collections/ehs-videos/videos 另有中文字幕版可向助教索取。
3. 計算機概論(computer)： http://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-00-introduction-to-computer-science-and-programming-fall-2008/index.htm
4. 雷射與光學(laser and optics)：http://ocw.mit.edu/resources/res-6-005-understanding-lasers-and-fiberoptics-spring-2008/ 和 http://ocw.mit.edu/resources/res-6-006-video-demonstrations-in-lasers-and-optics-spring-2008/另有中文字幕版可向助教索取。
5. 演示實驗(demonstration)：http://sciencedemonstrations.fas.harvard.edu/icb/icb.do

線上論壇 (Online forum)

喬治查爾斯電子電路網 http://gc.digitw.com/
Java Gossip http://openhome.cc/Gossip/JavaGossip-V1/
Stack Overflow http://stackoverflow.com/
Processing 官網 http://processing.org/
Arduino 實作 http://coopermaa2nd.blogspot.tw/

第一學期專案範例 (project examples for the first semester):

專案 project	工作內容 content	目標 goal
偵蒐鼠 reconnaissance mouse	1. 數據網路遙控操作 remote operation via mobile data network 2. 聲音影像傳輸 transmission of voice and image 3. 偵測瓦斯、氧氣含量 detecting gas and oxygen concentration 4. 使用者介面設計 user interface design	可上下樓梯，可轉動門把，可傳輸影像、聲音、溫度、毒性氣體數據。Can climb stairs, open a door by turning the handle, transmit voice, image, temperature, data of gas composition.
電子伸縮號 electronic trombone	1. 超音波測距或雷射測距以控制音符 real-time distance measurement by ultrasonic wave or laser to control the note 2. 以 MIDI library 產生音波 producing trombone notes by using MIDI library 3. 以吹氣力道偵測來控制音色 using blow force detection to control the tone	實作出一支電子伸縮號，可記錄成 MIDI 檔案並重播。Making an electronic trombone that can record the performance in MIDI file and replay.
電子套鼓 electronic drum set	1. 使用壓電元件偵測打擊力道 using Piezoelectric elements to detect the strength of hit. 2. 以 MIDI library 產生音波 producing drum beats by using MIDI library	實作出一組電子套鼓，可記錄成 MIDI 檔案並重播。Making a drum set that can record the performance in MIDI file and replay.

雷射定向電話 directional laser telephone	1. 使用二極體雷射傳輸訊號 using diode laser to transmit signal 2. 使用 pulse-width modulation 載入訊號 using pulse-width modulation to encode analog signal	實作出一組可傳輸 1 公里的雷射定向電話 making a directional laser telephone that can transmit signals across 1 km.
磁力懸浮機 Magnetic suspension	1. 使用電磁線圈和 PID 回授控制達成磁力懸浮 Using electric coil and PID feedback control to achieve magnetic suspension 2. 使用發光二極體或雷射或超音波偵測位置誤差 Use LED, laser, or ultrasound to detect position deviation and apply magnetic force to correct it.	1. 三個維度的捕捉範圍都達到 1 cm Trapping range reaches 1 cm in all three dimensions 2. 可連續工作，無線圈過熱問題。 Working continuously without over heating the coil.
虛擬單車旅遊 Virtual bicycle tour	1. 將單車改裝為具有發電功能的室內健身器 Modify a bicycle to an indoor exercise bike and couple it to an electric generator 2. 使用 Google 街景服務與單車連動。Link Google street view to the bike	1. 發電可驅動電扇，模擬單車的迎風 The generator drives a fan to simulate the head wind. 2. 透過網路同步兩輛單車，模擬二人同遊 Synchronize two bikes over the internet to simulate two person traveling together
機械鞦韆 Mechanic swing	不外加轉矩而能自我振盪的機械鞦韆 A self-starting and propelling	1. 驗證鞦韆的理論 Verifying the theory of swing

	swing without applying torque	2. 能夠愈盪愈高，甚至從擺盪轉為圓周運動。Swing higher and higher until the swing oscillation becomes rotation
電磁軌道槍 Electromagnetic rail gun	1. 處理大電能的儲存問題和大電流的開啟導通問題 Handling large electric energy storage and large electric current switching 2. 處理拋射物與軌道的磨擦問題 Handling the friction between the projectile and the rail	1. 驗證電磁理論 Verifying the electromagnetic theory 2. 性能與奧運10米空氣手槍相仿。Performance comparable to ISSF 10 meter air pistol
雷射槓桿竊聽器 Tapping with laser lever	1. 相片框受到音波而振動，造成雷射光束偏向。A picture frame vibrates by sound wave and deflects a laser beam. 2. 光偵測器從雷射的偏向抖動還原相框的振動和聲音。A light detector retrieves the vibration and sound wave from the shaking laser beam.	穿過隔音玻璃竊聽對話。Tapping conversations through sound-proof glass
Wimshurst machine	手動高電壓直流發電機 Hand-operating high voltage generator	古人可建造的電蚊拍 A mosquito swatter that could be made by our ancient ancestors

第二學期專案範例 (project examples for the second semester):

專案 project	工作內容 content	目標 goal

驗證萬有引力定律並測量重力常數 Verify the law of gravitation and measure the gravitational constant		
驗證庫倫定律並測量真空的介電常數 Verify the Coulomb law and measure the vacuum dielectric constant		
驗證法拉第感應定律和馬克士威爾－安培定律 Verify the Faraday law and the Maxwell-Ampere Law		
改良 Hertz 的實驗，測量 RF 電磁波(非光波)的波長 Improve the experiment of Hertz for measuring the wavelengths of radio waves		
Hanbury-Brown-Twiss experiment		
Kelvin-Helmholtz 不穩定性實驗 Experiment with Kelvin-Helmholtz instability		
測量普蘭克常數 Measure the Planck constant		
測量光速 Measure the speed of light		
Rayleigh scattering		

測量波茲曼常數 Measure the Boltzmann constant		
測量地球到月球的距離 Measure the distance between the earth and the moon		
瓦特天平 Watt balance		以電磁力定義質量 define mass by using electric magnetic force