

关于基础物理实验教学的模式思考与改革探索

历史、现实与挑战

探索研究型的基础物理实验教学模式

北京大学物理学院基础物理实验教学中心 李智

(辽宁省高等学校物理类专业实验建设在线研讨会)

一、概述

我们的团队与任务

共16人 { 专职实验教师：9人（3教授+6副教授），教学
工程技术人员：7人（1高工+6工程师），教辅

- (1) 教学工作：专职教师工作量大于教研系列人员的两倍工作量。
- (2) 组织教学：每年百人次的兼职教员。
- (3) 课程建设：教材、实验室、仪器设备、教学改革。

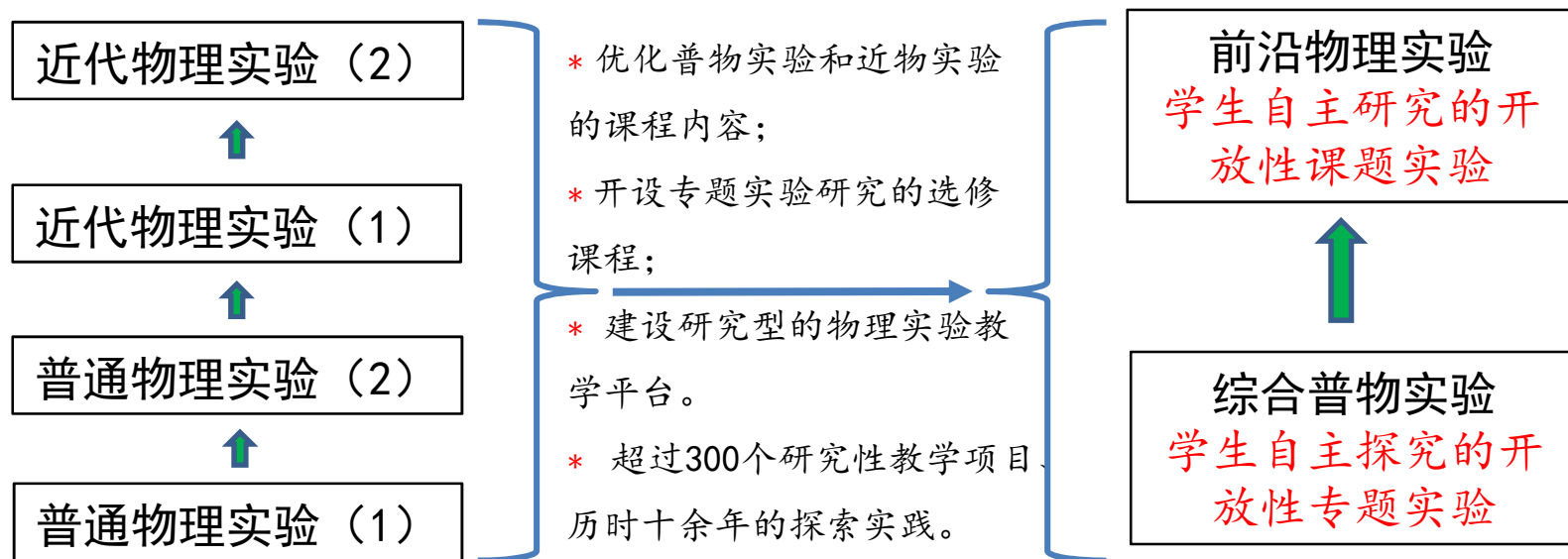
学生 { 物理类：两学期普物（128学时）+两学期近代（128学时）
非物理类：一学期基础实验（64学时）

我们的课程与改革实践

普通物理实验：国家级精品课、国家级精品资源共享课

近代物理实验：国家级精品课

面向物理学研究的前沿，审视和发展物理实验教学



将科研模式转化为教学模式，引入“强化学生自主探究”的“开放性实验”教学。

二、发展历程

北大物理实验教学的传统与变革

1952年院系调整，学习苏联教学经验，确立物理实验教学模式：

- 教学目的：

“介绍给学生用实验的方法研究物理学”

- 教学体系：

“普通物理实验→专门物理实验→专门化物理实验”

- 教学组织单位：“教学研究室”，简称“教研室”

普通物理实验 → 专门物理实验 → 专门化物理实验

(1952-1956)



中级物理实验

(1956-1966)



近代物理实验

(1978-至今)

与时俱进，
优化更新



宽口培养，
淡化专业



1978年后：普通物理实验+近代物理实验



普通物理实验

出版了全国第一本普通物理实验教材（1981年）。
1989年国家级优秀教学成果特等奖。2006年国家级精品课。2014年升级为国家级精品资源共享课。



近代物理实验

出版了全国第一本近代物理实验教材（1986年）。

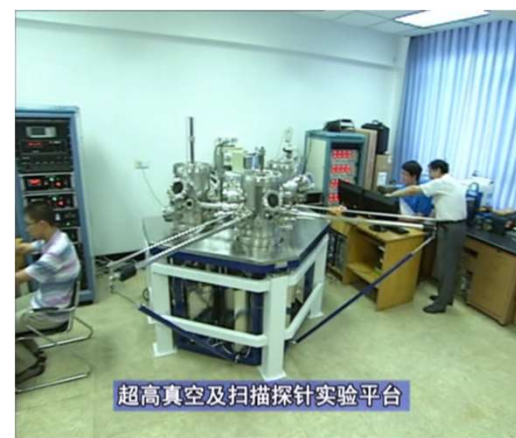
1993年国家级优秀教学成果一等奖。2003年国家级教学名师奖（吴思诚）。2007年国家级精品课。

科研对教学的影响

科研，特别是本科生科研，倒逼实验教学的改革与创新

- 科研引领教学，势在必行
- 站在科研高端，开展实验教学
- 面向科学研究，梳理教学体系

研究型创新实验教学平台建设

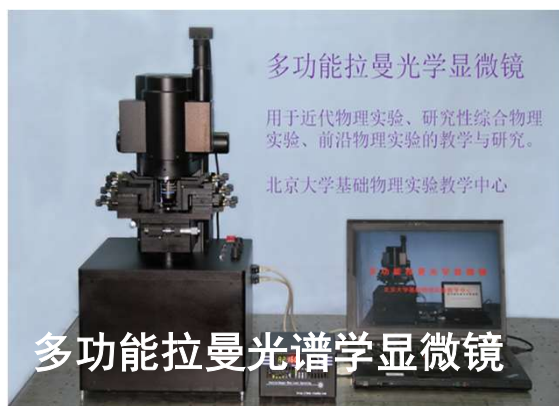


改造、购置、自建科研级大型设备， 深化研究性物理实验教学，强化科研引领教学的理念

购置：



自建：



2016年获得第九届全国高校物理实验教学研讨会**实验仪器评比一等奖**

开课时间	实验题目	指导教师	选课学生
01 年秋	测量 PIN 光电二极管的光谱特性和量子效率	张洁天	王锡华 林国基
01 年秋	计算机 I/O 接口实验	张洁天	刘丹 高锦华
01 年秋	计算机串行口数据传送与处理	张洁天	路欣 胡涛
01 年秋	用光电开关制作条形码读出器	张洁天	陈亦飞 施展
01 年秋	用光电开关测量人体心率波形分析	张洁天	方文娟 李犁
01 年秋	数字合成任意波形信号发生器	张洁天	李何文 郝庆

12 秋			
学生	导师	课题方向	奥亚竞赛
张雪萌	周路群	法拉第堆的相关研究	
戴 极	周路群	振荡系统下的粘稠流体对流斑图研究	
吕廷博	周路群	对流斑图移动原因的半定量研究	✓
王立平	周路群	对流斑图移动原因的定量研究	

周楠	周路群	一维非线性系统表面驻波现象研究		✓
14春				✓

普通物理实验层次的“研究型课题实验”

近代物理实验课-大实验题目汇总

开课时间	实验题目	指导教师	选课学生
02 年秋	多层膜的制备和 x 射线衍射分析	荀坤	赵北北 贾琦
02 年秋	卢瑟福背散射分析薄膜成分	荀坤	蔡金明 李亮
02 年秋	高温超导样品制备过程中热电势的测量	冯庆荣	周卓为 周良玉
02 年秋	高温超导样品制备过程中电导率的测量	冯庆荣	陈鑫 詹凯
02 年秋	?	杜为民	张森 白凡
02 年秋	?	11 年秋	电子束曝光机改装及 MgB ₂ 薄膜超导性能研究
04 年秋	CVD 法制	11 年秋	电子束曝光法制备 MgB ₂ 的最佳温度调节实验
04 年秋	微型制	11 年秋	电子束曝光法制备 MgB ₂ 的最佳 Mg, B 配比
04 年秋	理论密	11 年秋	溶液法制备 MgB ₂ 薄膜
04 年秋	有机纳	11 年秋	实时电阻采集器
04 年秋	Raman 谱	11 年秋	Al ₂ O ₃ 衬底上的 MgB ₂ 超薄膜的制备与性质研究
04 年秋	研究	11 年秋	SiC 衬底上的 MgB ₂ 薄膜制备及生长过程研究
04 年秋	Raman 谱	11 年秋	石墨烯与拓扑绝缘体 Bi ₂ Te ₃ 界面性质拉曼谱研究
04 年秋	Raman 谱	11 年秋	位置灵敏塑料闪烁体探测器的研究和设计
04 年秋	Raman 谱	11 年秋	CsI (Tl) 谱仪的能量分辨研究
04 年秋	Raman 谱	11 年秋	单等离激元纳米结构的制备表征及其应用： 单个等离激元纳米结构的生物传感器
05 年秋	MgB ₂ 超	11 年秋	单等离激元纳米结构的制备表征及其应用：
06 年秋	MgB ₂ 超	11 年秋	单等离激元纳米结构的制备表征及其应用：
06 年秋	用热激	11 年秋	单等离激元纳米结构的制备表征及其应用：
07 年秋	MgB ₂ 超	11 年秋	单等离激元纳米结构的制备表征及其应用：
07 年秋	纳米金	11 年秋	单等离激元纳米结构的制备表征及其应用：
07 年秋	量	11 年秋	单等离激元纳米结构的制备表征及其应用：
07 年秋	ReCu ₂ 中	11 年秋	单等离激元纳米结构的制备表征及其应用：
08 年秋	表面浸	11 年秋	单等离激元纳米结构的制备表征及其应用：
08 年秋	ZnO 纳	12 年秋	复合纳米核壳结构的拉曼探针的制备
08 年秋	Cs 元素	12 年秋	FeMn/Co 双层膜体系的交换偏置效应研究
09 年秋	GaN 基	12 年秋	CdS/CdSe 异质结纳米线(带)制备及其光电特性表征
09 年秋	大功率	12 年秋	硅基混合激光材料和激光器
09 年秋	二硼化	12 年秋	MgB ₂ 超薄膜制备及性质研究
09 年秋	性测量	12 年秋	利用石墨烯和氧化铋
10 年秋	纳米科	12 年秋	多层 CVD 石墨烯的制备
10 年秋	超高真	12 年秋	LaAlO ₃ /SrTiO ₃ 界面二维
10 年秋	MgB ₂ 超	12 年秋	金属氧化物对有机光电致
10 年秋	约瑟夫	12 年秋	基于介观光学结构的有
10 年秋	薄膜场	12 年秋	固体燃料敏化太阳能电
10 年秋	有机电	12 年秋	石墨烯纳米材料及器件
10 年秋	非极性	12 年秋	石墨烯纳米材料及器件
10 年秋	Rare-ear	12 年秋	低温控制系统的电路设
10 年秋	optical	12 年秋	低温控制系统的电路设
		12 年秋	利用 CVD 法生长石墨烯
		12 年秋	利用音叉式原子力扫描
		12 年秋	利用音叉式原子力扫描
		12 年秋	超导隧道节中噪声的测
		12 年秋	碳原子在二维碳纳米材

前沿物理实验汇总 (2014 春季-2017 春季)

学期	学生	导师	课题名称
14 年春季学期	程明昊	吴孝松	高真空变温电学测量系统的搭建
	谢可平	李强	LHC 上 CMS 实验的大规模数据处理
	朱逢源	林峰	表面等离激元全息技术研究
	王天乐	方哲宇	金属表面等离激元增益波导及调控研究
14 年秋季学期	叶梓丹	方哲宇	金属表面等离激元增益波导及调控研究
	龚宗平	王健	新型拓扑材料和低维超导材料的探索
	闾星陆	肖立新	基于介观光学结构的有机发光器件
	严乔婧	周治平	Polarization insensitive strip-slot mode converter
	王士博	王新强	InN 量子点在高 In 组分 InGa _N 层上的 MBE 生长及其性质研究
	邱紫薇	王新强	面向高性能光电器件的氮化物半导体量子盘结构的分子束外延生长
	杨帆	廖志敏	拓扑金属材料 Cd ₃ As ₂ 的制备与输运测量
	蔡新强	张朝晖	从室温到高温, 石墨烯拉曼光谱演变的实验研究
	罗州宸	肖立新	基于介观光学结构的有机发光器件
	李思尘	廖志敏	拓扑半金属纳米材料的制备与物性研究
	朱鸿轩	肖池阶	等离激元磁探针的研制及相关诊断
	叶伟成	王新强	氮化物半导体单光子源
15 年秋季学期	桂贵	任泽峰	二次谐波带压压缩
	单君翌	张家森	基于金属腔的纳米激光器研究
	宁鸿烈	王健	拓扑超导体候选材料的探索
	叶伟成	王健	拓扑超导材料的制备和表征
16 年春季学期	李其楠	李焱	介电超表面诱导的内生和外生光自旋霍尔效应
	钟昕锐	肖立新	非铅钙钛矿材料
	向鹏展	廖志敏	二维材料 NbSe ₂ 的制备和物性研究
	乔宽	马仁敏	钙钛矿光电器件研究
	曹捷	陈剑豪	超薄 FeTe ₂ 场效应管的磁输运测量
	刘运全		原位干涉自相关、互相关脉宽测量仪
	陈剑豪		Ti ₂ O ₃ 薄膜掺杂的原位输运测量
	王健		新型拓扑材料与超导材料
	王健		铜氧化物超导材料
	肖云峰		光学微腔对金属纳米颗粒耗散性质调制
	肖云峰		非线性诱导的单向拉曼激光
	江颖		THz-STM 搭建与针尖场增强机制探究
	林熙		交流热输运中的低温温度计
	刘运全		基于飞秒激光自相关测量的脉宽反馈控制
	叶培		二维异质结构界面的奇异物性调控
	吴孝松		石墨烯自旋阀器件的制备

近代物理实验层次的“研究型课题实验”

13 年秋	石墨烯/氧化铋异质结构光电性质研究	廖志敏	陈少闻
13 年秋	石墨烯 PN 结的制备和物性研究	廖志敏	盛典
13 年秋	基于氧化铁纳米体系的能源转化器件研究	赵清	杨婧
13 年秋	环形硅微条探测器的性能测试	楼建玲	黄彦琦
13 年秋	3×3 英寸 NaI(Tl) 探测器的性能测试和模拟	楼建玲	曲慧麟
13 年秋	高 Al 组分 AlGa _N 及其低维结构微结构和光学性质	许福军	宋翔宇
13 年秋	载流子通过隧道结的输运测量和统计分析	危健	陈一
13 年秋	3He 制冷系统外围设备的改造	张弛	吴蒙
13 年秋	3He 制冷系统外围设备的改造	张弛	柯伟尧
13 年秋	拓扑绝缘体纳米样品的制备与物性	王健	马达
13 年秋	拓扑绝缘体纳米样品的制备与物性	王健	宋化鼎
13 年秋	基于微纳结构的有机光电子器件研究	肖立新	孙思白
13 年秋	基于微纳结构的有机光电子器件研究	肖立新	罗巍
13 年秋	扫描近场光学显微镜研究表面等离激元的调制传播	林峰	马骁
13 年秋	扫描近场光学显微镜研究表面等离激元的调制传播	林峰	严梦媛

Efficient Directional Excitation of Surface Plasmons by a Single-Element Nanoantenna

Wenjie Yao,^{1,2} Shang Liu,^{1,2} Huimin Liao,^{1,2} Zhi Li,^{1,2} Chengwei Sun,^{1,2} Jianjun Chen,^{1,2} and Qihuang Gong^{1,2}¹School of Physics, Peking University, Beijing 100871, China²State Key Laboratory for Mesoscopic Physics, Peking University, Beijing 100871, China

Supporting Information

ABSTRACT: Directional research and real applications of optical antennas. Here, by adding single-element plasmonic efficient lowest-order antenna into inactive higher-order conversion, scattered optical utilizing the interference broadband directional excitation (SPPs) and inversion of S. The proposed strategy has optical devices, especially in

KEYWORDS: nanoantenna

Nanoscale

PAPER

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Efficient unidirectional launching of surface plasmons by a cascade asymmetric-groove

Journal of the
Optical Society
of America
B

OPTICAL PHYSICS

Quasi-cylindrical waves on a dielectric-film-coated metal surface

Heming Wang,¹ Xin Chen,² Siyuan Wei,¹ Fan Yang,¹ Huimin Liao,¹ Zhi Li,^{1,2} Jianjun Chen,^{1,2} and Qihuang Gong^{1,2}¹School of Physics, Peking University, Beijing 100871, China²State Key Laboratory for Mesoscopic Physics, Peking University, Beijing 100871, China^{*}Corresponding author: z_li@pku.edu.cn

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In addition to surface plasmon polaritons (SPPs), quasi-cylindrical waves on a dielectric-film-coated metal surface are changed when the coating is rapidly. These different CW waves are, respectively, and related analyses with CWs.

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APPLIED PHYSICS LETTERS 105, 231101 (2014)

Unidirectional launching of surface plasmons at the subwavelength scale

Yifei Zhang,¹ Heming Wang,¹ Huimin Liao,^{1,2} Zhi Li,^{1,2} Chengwei Sun,^{1,2} Jianjun Chen,^{1,2} and Qihuang Gong^{1,2}¹School of Physics, Peking University, Beijing 100871, China²State Key Laboratory for Mesoscopic Physics, Peking University, Beijing 100871, China

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Broadband Surface Plasmon Polariton Directional Coupling via Asymmetric Optical Slot Nanoantenna Pair

Jing Yang,¹ Xiao Xiao,¹ Chuang Hu,¹ Weiwei Zhang,¹ Shuzhang Zhou,¹ and Jiasen Zhang^{1,2}¹State Key Laboratory for Mesoscopic Physics, Department of Physics, Peking University, Beijing 100871, China²Collaborative Innovation Center of Quantum Matter, Beijing 100871, China

Supporting Information

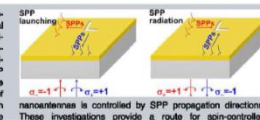
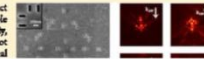
ABSTRACT: Surface plasmon polariton (SPP) coupling is a basic subject for plasmonic study and applications. Optical nanoantennas enable downscaling of the SPP coupling to subwavelength scales. In this study, asymmetric optical slot nanoantenna pairs composed of two optical slot nanoantennas with different lengths are proposed for SPP directional coupling. Broadband unidirectional excitation ratio obtained was larger than 157%. First demonstrated using the asymmetric plasmonic display device is achieved by employing an asymmetric pair of compact optical circuits and

KEYWORDS: Surface plasmon polariton

LASER & PHOTONICS REVIEWS

Laser Photonics Rev. 8, No. 4, 590–595 (2014)/DOI 10.1002/lpor.201300201

Abstract: Broadband spin-controlled surface plasmon polariton (SPP) launching and radiation via L-shaped optical slot nanoantennas are proposed and demonstrated experimentally. The phase retardation and spectra overlapping between two resonant plasmon modes in the L-shaped optical slot nanoantenna lead to the origin of this effect. SPP launching in two perpendicular directions are controlled by the spin of the incident light. Broadband directional launching of SPPs is achieved and the extinction ratio keeps larger than 7 dB within a wavelength range of 180 nm. Furthermore, the photon spin of SPP radiation



Broadband spin launching and radiation via asymmetric optical slot nanoantennas

Jing Yang¹, Shuzhang Zhou¹

Plasmonic polarization nano-splitter based on asymmetric optical slot antenna pairs

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We propose and experimentally demonstrate polarization nano-splitter based on asymmetric optical slot antenna pairs. unidirectional surface and splitting are achieved by controlling the spin of the incident light.

Photonics (2016) 10:1551–1556
DOI: 10.1007/s11464-015-9970-4

Surface Plasmon Polariton Unidirectional Nano-Launcher Based on the Strong Coupling Effects in an Asymmetric Optical Slot Nanoantenna Pair

Kenzhuo Huang¹, Jing Yang¹, Xiao Xiao¹, Jiasen Zhang^{1,2}Received: 29 January 2015 / Accepted: 8 May 2015 / Published online: 16 May 2015
© Springer Science+Business Media New York 2015

Abstract: We investigate the strong coupling effects in asymmetric optical slot nanoantenna pairs (AOSNPs) consisting of two parallel positioned optical slot nanoantennas with different lengths and propose a surface plasmon polariton (SPP) unidirectional nano-launcher based on the strongly coupled

Introduction

Surface plasmon polaritons (SPPs) are confined electromagnetic fields propagating along the metal-dielectric interface, which arise from the coupling between photons and free

通过研究型课题实验，培养了优秀本科生的科研能力，中心的年轻教员快速成长。

文章编号:1005-4642(2018)03-0024-04



以“科研引领实验教学”理念,推动物理实验 教学的改革和团队建设

李 智,张朝晖

(北京大学 基础物理实验教学中心,北京 100871)

摘 要:北京大学基础物理实验教学中心以“科研引领实验教学”理念推进科研和教学的全面融合,调整课程体系,推动物理实验教学改革,取得了较好的教学效果.

关键词:大学物理实验;教学改革;科研

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1、挑战与机遇

2、探索与实践

3、成效与展望

传
基本理
系列的

学模式
的科研,
学进行

三、新的探索

新的问题

上限很高，
下限如何保证？



创新教学

基本教学
质量有保证



传统教学



平衡

教学理念、教学模式、教学体系

综合普物实验课程简介

（一）课程理念

综合普物实验力求突出其课程内容的综合性，这不仅包括基础物理和技术的综合，也包括基础物理与前沿应用的融合。

综合普物实验力推学生自主实验的开放研究模式，教员退居后台，通过编写的实验辅助教程和面谈交流，引导学生尽可能地进入一个个复杂的实验环节，最后完成丰富的实验内容，并且争取有所创新。

（二）实施方案

1. 综

实

2. 该

成

3. 学

人

4. 课

半

于

期

5. 关

确

6. 课程考核：实验室成绩（40%）+ 面谈成绩（20%）+ 论文报告成绩（20%）+ 口头报告成绩（20%）。实验室成绩由实验室技术人员给出，面谈成绩由和学生面谈的教员给出，两者最后的成绩分别是6组实验得分的平均值。两个报告的成绩分别是所有教员打分的平均值。最终的学习成绩登录到普通物理实验（2）。

7. 每组实验都具有综合性的实验内

（三）实验项目

本学期开设以下6组实验：

（1）光学成像与光信息处理；

（2）迈克耳逊干涉仪与光学相关测量；

（3）基于虚拟仪器技术的弗兰克-赫兹实验；

（4）光力学效应及光镊实验；

（5）一维周期弦链系统振动模研究；

（6）二维法拉第斑图实验观察与研究。

“综合普物实验”课程的理念、模式和教学实践

面向普通物理实验（1）成绩优秀的学生，按学生意愿由高分到低分录取，实录上课人数不超过上普通物理实验（1）总人数的15%。

面向优秀学生开课

学生自主探究的开放性专题实验，没有教员现场指导



基于虚拟仪器技术的F-H实验



二维法拉第斑图实验



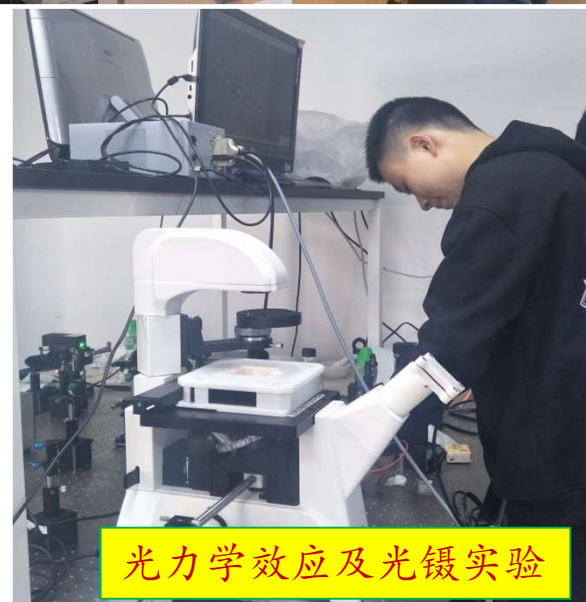
光学成像与光信息处理



迈克耳逊干涉与相关测量

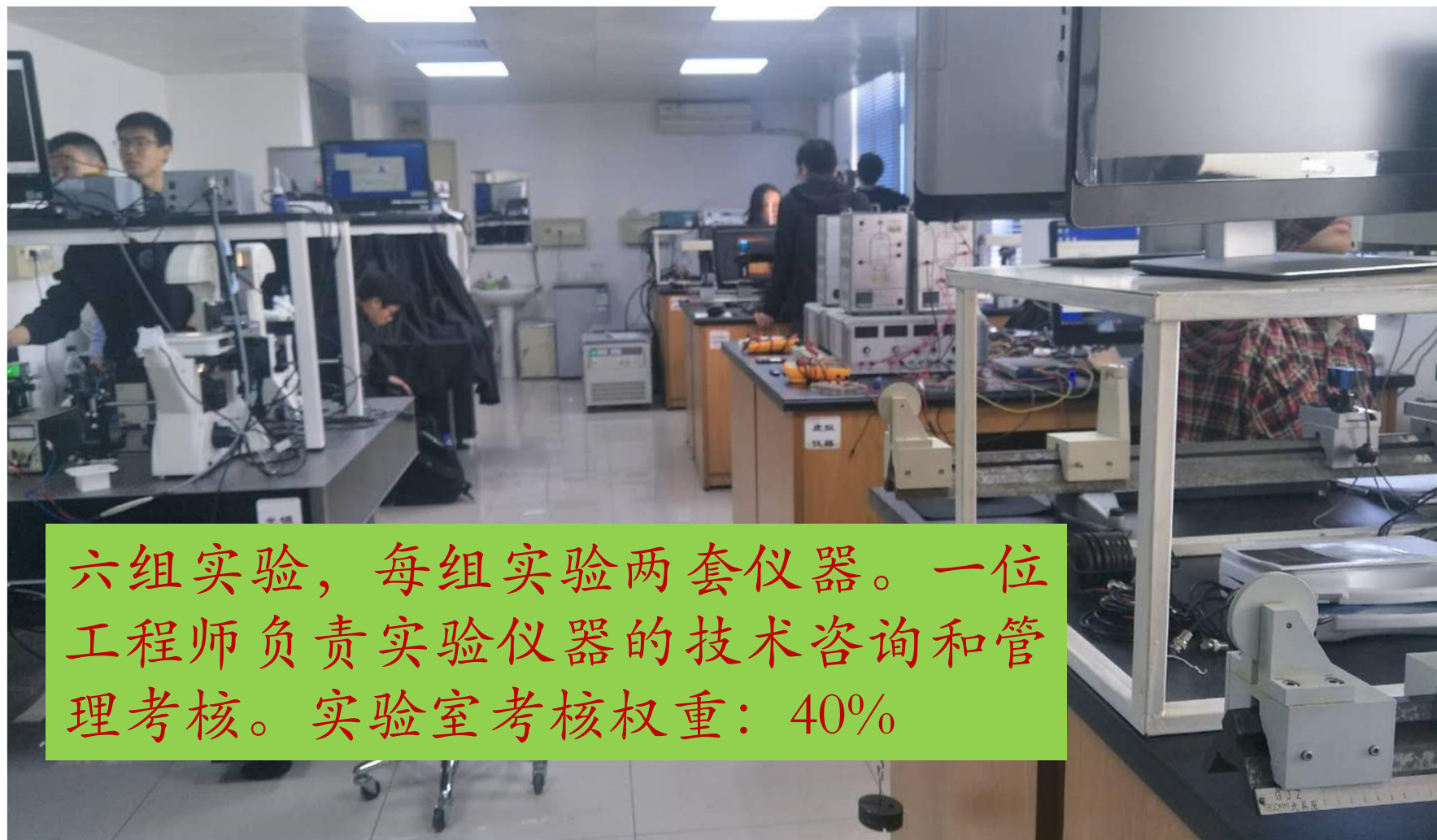


一维周期弦链系统振动



光力学效应及光镊实验

所有实验在一个实验室循环进行，鼓励学生相互交流



六组实验，每组实验两套仪器。一位工程师负责实验仪器的技术咨询和管理考核。实验室考核权重：40%

教员如何指导学生的实验？

- ✓ 提供基本的实验参考资料（没有教材）。
- ✓ 一对一面谈交流，解决问题，考核完成实验的情况。
- ✓ 出席期中、期末的口头报告会，对每位学生的口头做成绩评定。
- ✓ 阅读期中、期末的书面论文，对每位学生的书面论文做成绩评定。

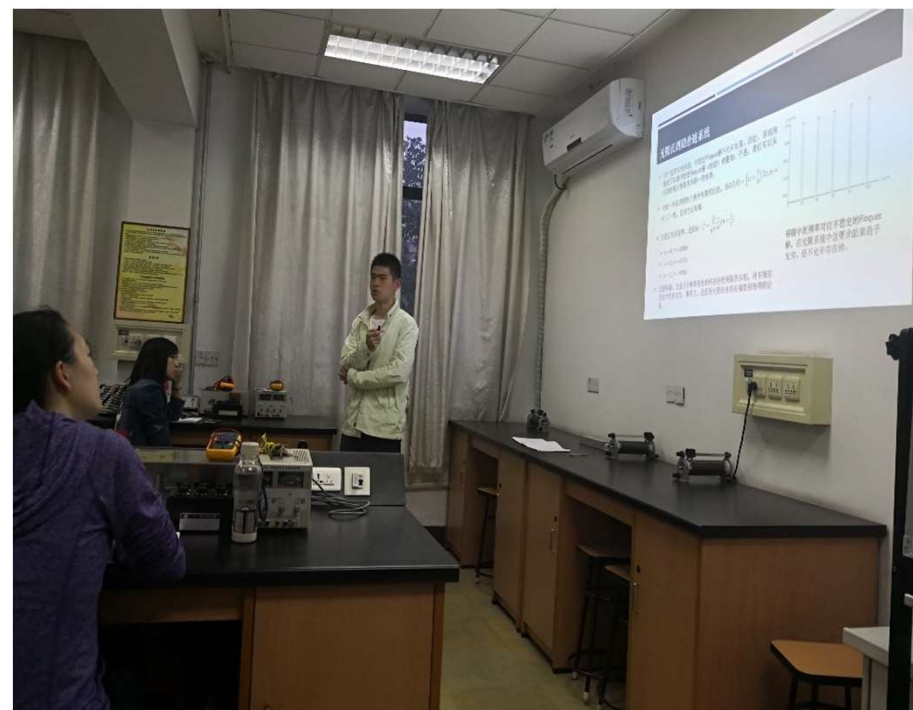
面谈指导很重要！

学生每两周完成一个实验，每周实验后必须与教员有一次面谈。面谈考核成绩：12次面谈成绩的平均值。考核权重：20%。

专题研究，口头报告：

期中一次，12/24人；期末一次，12/24人。按学术报告的规范，要求学生报告就课程实验相关的一个问题所做的深入研究，15分钟报告+5分钟提问。

考核权重：20%。



Attempts to Capture
Nodes & Antinodes
of Faraday Pattern



欧阳筱羿 1600011385

Quantifying Faraday Pattern and Onset Region of Fluid
with NMF and 2PCF Algorithms

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Advanced Physics Experiment
June 12th, 2018

探究弗兰克-赫兹实验中温度参量对极板
电流的影响及其机理

物理学院 赵彤阳
2018/06/16

低浓度下浅层法拉第斑图的
探究



唐清霖

激光标定的傅里叶变换光谱仪
一种有效减少相位噪声的手段

茆峻 1600011373@pku.edu.cn

2018 年 6 月 16 日

低频条件下的法拉第斑图选择问题研究

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指导老师: 周路群老师 王伟老师

2018.06.16

实验结果优化和白光干涉的应用
——迈克耳逊干涉仪与光学相关测量

地球与空间科学学院
侯传鹏
2018.6.16

采样定理
在光信息处理中的应用

报告人: 乔天宇 指导教师: 张朝晖
北京大学物理学院
2018-6-16

Modeling and Simulation of
Franck-Hertz Experiment

Reporter: Chen Yingtian Instructor: Li Zhi

期中一次，12/24人；期末一次，12/24人。按学术论文的规范，要求学生就课程实验相关的一个问题做深入研究，提交一篇研究论文。考核权重：20%。

[3] 王光烈, 孙根史, 梁秀娟等. 物理化学实验“圆重法测定液体表面张力”改革方案设计与实践[J]. 广东化工, 2010, 37(11): 169-170.

Quantifying Faraday Pattern and Onset Amplitude of Fluid with NMF and 2PCF Algorithms[†]

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Department of Astronomy

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(Dated: June 16, 2015)

I. INTRODUCTION

Nature often exhibits Faraday pattern, chaotic Faraday pattern, random Faraday pattern, or Faraday pattern. Faraday pattern is a nonlinear phenomenon that occurs in the surface of fluid when the container is subjected to a vibrating resonator. Patterns include stripes, squares, hexagons, and under special parameters, one can also observe other non-symmetrical patterns such as multi-frequency hexagonal patterns, quasi-patterns (Christiansen et al., 1992; Edwards & Pearce, 1994), superlattice patterns (Sillars & Fowles, 2006; Fowles, 2007; Sillars et al., 1998), spatio-temporally irregular patterns, modulated hexagonal disorder, two-mode superlattice and unidirectional states (Arnold & Poincaré, 1986; Arnold & Poincaré, 2000), and double hexagon states (Arnold & Poincaré, 1986).

Since it is impossible to explicitly write down closed-form solution of the complete Navier-Stokes equations for the Faraday pattern, an alternative approach is to apply weakly nonlinear analysis within the vicinity of onset. It is known that nonlinear three-wave resonant interaction plays a key role in pattern selection in Faraday wave experiments (Edwards & Pearce, 1994; Marston et al., 1995; Newell & Passera, 1999; Passera & Sillars, 2003). After applying multiple-scale analysis and simplifying with symmetry, one can arrive with a amplitude equation

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frequency domain, while energy of high frequency component is distributed in the peripheral region. If 2DPT is applied onto a perfect image with smoothly distributed noise, a prominent ring in frequency plane can be found. But in this experiment, wave patterns are sometimes not homogeneous and tend to have locally uniform distribution in relatively small region, and patterns in different regions are in different modes and along different directions. Thus 2DPT method would be contaminated by low-frequency and high-frequency noise.

To measure the wavelength with higher precision, we refer to a well-developed method in seismology and astrophysics to depict the characteristics of fluctuations in the density field, namely the two-point correlation function (2PCF). Two-point correlation function has been used in cosmology research, especially in cosmic microwave background (CMB), baryonic acoustic oscillation (BAO), galaxy clusters and dark matter halo (Peebles, 1980). Two-point correlation function detects the extent probability to find a point over random distribution. If data points are clustered in a given space, two-point correlation function can tell the inter-cluster spread and inter-cluster separation (Peebles, 1980; Gatti et al., 2012). The bootstrap 2PCF method can also calculate degree of correlation function. After NMF decomposition, we choose green channel or blue channel (representing mode and azimuth) according to the degree of decomposition. Peak inside of the circular contour whose gray level are higher than 200 are marked as data points. Then we calculated 2PCF of these data points using autoM and obtain $\langle \xi(r) \rangle$ as shown in Fig. 6. Equivalent peak only patterns have good periodic structure. The position of first peak is inter-cluster distance, i.e. wavelength λ , in this work.

Let δS be an infinitesimal area so that the probability of finding one data point in δS is $\langle \xi(r) \rangle \delta S$. Under the first order approximation, the probability of finding a point in area δS is

$$\delta P = n \delta S, \quad (14)$$

where n is a constant (i.e. number density). Then δP and n depend on the position of δS . The probability of finding a point in δS_1 and another in δS_2 with separation r is

$$\delta P_{12} = n \delta S_1 \delta S_2 (1 + \langle \xi(r) \rangle), \quad (15)$$

The estimate of $\langle \xi(r) \rangle$ represents the aggregation behavior of data points in the given plane. If the points are randomly correlated and distributed randomly, then $\langle \xi(r) \rangle = 0$. If $\delta P_{12} > \delta P$, then $\langle \xi(r) \rangle$ is called as nontrivial bility $A(r, 2) = P(A)/[P]^2$, where A has already found a point in δS_1 , then the probability of finding the corresponding point in δS_2 is

$$\delta P_{12} = n \delta S_1 (1 + \langle \xi(r) \rangle), \quad (16)$$

We can integrate δP_{12} inside an area S , where S is a circle with center at r_1 and radius r .

$$N(r) = n \pi r^2 (1 + \langle \xi(r) \rangle), \quad (17)$$

Note that $\langle \xi(r) \rangle$ is the function of the position of first point r_1 . If we know $\langle \xi(r) \rangle$, we can repeat the calculation in (17) using different first point r_1 and then calculate $\langle \xi(r) \rangle$ as an average. Taking the ensemble average of all such calculations give

$$\langle N(r) \rangle = n \pi r^2 (1 + \langle \xi(r) \rangle), \quad (18)$$

tion and acceleration relations are derived and simulated for different physical parameters. In section VII, the dependence between theory and experimental result are discussed.

II. BRIEF THEORY REVIEW

Infinitesimal surface wave driving parametrically excited in the form of a damped Mathieu equation. Suppose the vibrating resonator produces a sinusoidal motion of angular frequency ω and amplitude A . The fluid will experience apparent gravity $g(t) = g - A\omega^2 \cos(\omega t)$ in the reference moving with the container. Let $x = [x_1, x_2]$ and y represent the horizontal and vertical Cartesian coordinates in the moving frame. Offshore $y = -d_0 + y_0 \sin(\omega t) = y_0 \sin(\omega t)$ correspond to the bottom boundary, rest height level and free surface, i.e. d being the depth of fluid layer and y_0 representing the vertical motion.

Consider Fourier space assuming no horizontal boundary, surface wave can be dynamically described by a damped Mathieu equation (Benjamin & Ursell, 1954; Ciliberto & Gollub, 1985)

$$\frac{d^2 \hat{u}}{dt^2} + 2\alpha \frac{d \hat{u}}{dt} + [\hat{u}] - F \cos(2\omega t) \hat{u} = 0, \quad (1)$$

where $\hat{u}(t) = \int_{-\infty}^{\infty} \hat{u}(k, t) e^{ikx} dk$, $\hat{u}(k, t)$ is the Fourier transform of infinitesimal motion, $\alpha = \nu k^2$ is the viscous attenuation, $\omega = \omega_0(k)$ is the angular frequency of linear wave without damping and without forcing, $F = F(k)$ is the dimensionless forcing, and k being the wave vector with module $k = |k|$. For capillary-gravity waves of surface tension σ and density ρ

$$\omega(k) = \sqrt{\frac{\sigma}{\rho}} k^{3/2} \tanh(kd), \quad F = F^2 / (g\rho + T^2)^2, \quad (2)$$

In (1), the damping coefficient α originates from the boundary dissipation and the viscous friction with the bottom in the case of shallow water. Free two gravity waves in the limit of small viscosity, we have (Huang, 1996; Hunt, J. N., 1964)

$$\alpha(k) = \nu k^2 \left[\frac{\cosh(2kd)}{\sinh(2kd)} + \frac{1}{8\rho} \frac{\partial^2 \rho}{\partial x^2} \frac{\partial^2 \rho}{\partial x^2} \right]$$

where ν is the kinematic viscosity.

An implicit dispersion relation could be derived from periodic solutions of (1). Such periodic solutions exhibit a series of resonance conditions for response to a given frequency ω (or $\omega/2$), such as being an integer (Arnsperg & Hergen, 1962). In practice, we replace ω with $\omega/2$, corresponding to sub-harmonic resonance. When the driving frequency ω is close to the resonance frequency, the response $\hat{u}(k, t)$ will be larger than $1/\alpha$. Substituting $\hat{u}(k, t)$ with $A \exp(i\omega t)$ in equation (2) will further simplify it into an autonomous form

$$K \hat{u} = 0, \quad K = \frac{1}{4} \left(\frac{\omega^2}{\omega_0^2} - 1 \right) - \frac{F}{4} \frac{\cosh(2kd)}{\sinh(2kd)}, \quad (3)$$

with center on central dipole. Given a driving frequency, dipole pattern only appear when the driving force is very low. Hence dipole pattern is in a weakly nonlinear region and can be depicted by (3).

To quantify the wavelength of dipole pattern, we employ polar transformation method using polarTransform (Matlab, 2015) python package. We denote the gray level of a pixel by L . After convert NMF decomposed image from RGB into gray level L , we apply polar transformation $(\theta, \rho, L) \rightarrow (r, \theta, L)$ to the gray image, we get the radial distribution of L for all directions $\theta \in [0, 2\pi)$. We denote gray level profile as $\langle L(r) \rangle$, where r is a single parameter. Then stacking $\langle L(r) \rangle$ was applied to their profile and it turned out the final gray level profile, see Fig. 8.

The profile here troughs and peaks. Using peak detecting tool PEAKUTIL (Dey & Vazir, 2017), position of peaks and troughs can be detected. At the same time, the mean separation of peaks can be fitted using least square method. Note that mean separation of peaks are derived from the gray scale image, so that the wavelength of dipole pattern is two times of the mean separation.

The dispersion relation of dipole pattern for each sample is shown in Fig. 9. We fit the dispersion relation using (2) and obtain $g_0 = 1.44 \text{ kg m}^{-3}$, $T/\rho_0 = 3.12 \times 10^{-3} \text{ s}^2 \text{ m}^{-1}$. Red line shows the predicted dispersion law by (2) with $g = 9.8 \text{ kg m}^{-3}$ and the same T/ρ_0 ratio as the fitted line. From Komen (2014), the surface tension of milk is $T = 40 \text{ mN/m}$ and the density of milk is $\rho = 1.035 \times 10^3 \text{ kg m}^{-3}$. The theoretical T/ρ_0 is $3.9 \times 10^{-3} \text{ s}^2 \text{ m}^{-1}$. This result coincide with our fitted parameter quite well. But the fitted gravity g_0 is almost a half of the 9.8 kg m^{-3} . We think the fitted gravity g_0 is a half of the real gravity without periodic driving force. Both data boundary and the driving force may affect the measurement of g_0 , but driving force has no effect on the value of T/ρ_0 .

The gray level profile of dipole pattern with driving frequency $\omega/2 = 20 \text{ Hz}$ and gray scale represent those detected peaks and troughs, respectively.

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Example of the dipole patterns of milk sample are shown in Fig. 7. We consider the term dipole pattern here to mean that the central region in NMF decomposed image is like a dipole, while the equiphase line are circle

using a standard perturbation scheme. Assuming $F \ll 1$ and $\alpha = O(F^2)$, we approximate dispersion for the sub-harmonic resonance ($\omega = \omega/2$) in (Haydenbach & Chandra, 2015)

$$\frac{d \hat{u}}{dt} - \left(\frac{\omega_0^2}{4} - \frac{\alpha}{2} \right) \hat{u} = F \frac{\partial^2 \hat{u}}{\partial x^2} + \frac{K \hat{u}}{4}, \quad (7)$$

where ω_0 is related to ω via (2). The plus-minus sign here results from two separate solutions from the original equation. Note that the approximation only holds accurate near onset region.

Next weakly nonlinear approximation can be applied to the region near onset. Assuming $|K| \ll 1$, $F = O(K^{1/2})$ and $\alpha = O(K^{3/2})$, analytical equation for the slowly modulated amplitude A takes the form (Meun, 1987; Miller, 1991; Zhou & Viana, 1997)

$$\frac{dA}{dt} + \frac{1}{2} \alpha A = -\frac{1}{2} K A, \quad (8)$$

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Next weakly nonlinear approximation can be applied to the region near onset. Assuming $|K| \ll 1$, $F = O(K^{1/2})$ and $\alpha = O(K^{3/2})$, analytical equation for the slowly modulated amplitude A takes the form (Meun, 1987; Miller, 1991; Zhou & Viana, 1997)

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where α is related to ω via (2). The plus-minus sign here results from two separate solutions from the original equation. Note that the approximation only holds accurate near onset region.

(Haydenbach & Chandra, 2015)

$$\frac{d \hat{u}}{dt} - \left(\frac{\omega_0^2}{4} - \frac{\alpha}{2} \right) \hat{u} = F \frac{\partial^2 \hat{u}}{\partial x^2} + \frac{K \hat{u}}{4}, \quad (7)$$

where ω_0 is related to ω via (2). The plus-minus sign here results from two separate solutions from the original equation. Note that the approximation only holds accurate near onset region.

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实验题目的基础性、综合性、开放性



基于虚拟仪器技术的F-H实验



二维法拉第斑图实验



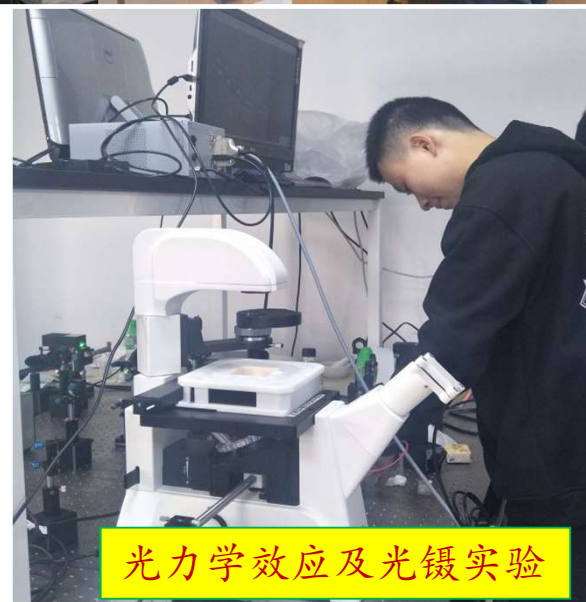
光学成像与光信息处理



迈克耳逊干涉与相关测量



一维周期弦链系统振动



光力学效应及光镊实验

举例：基于虚拟仪器技术的弗兰克赫兹实验

必做内容：编程、连线、变参数研究第一激发态、高激发态

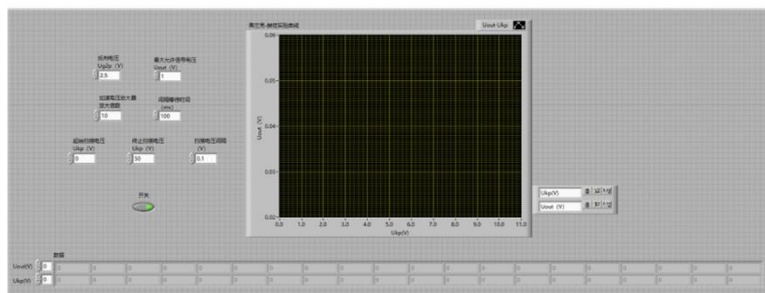


图 3-6 自动化弗兰克-赫兹实验前面板图

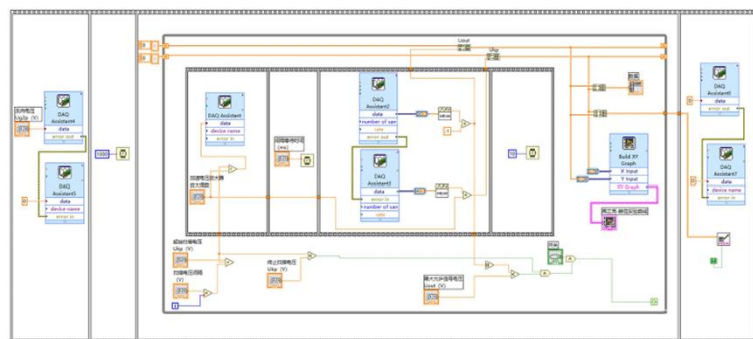
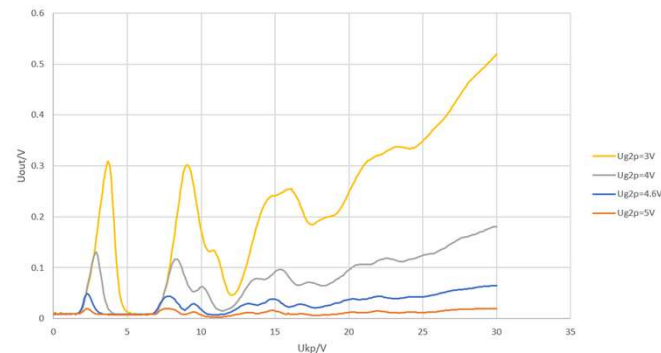
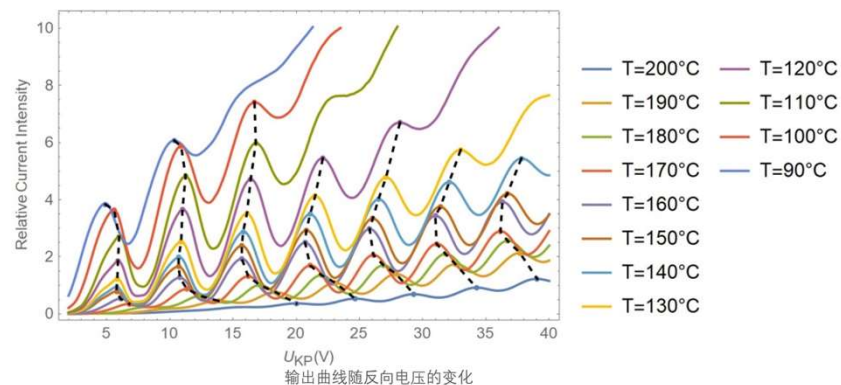
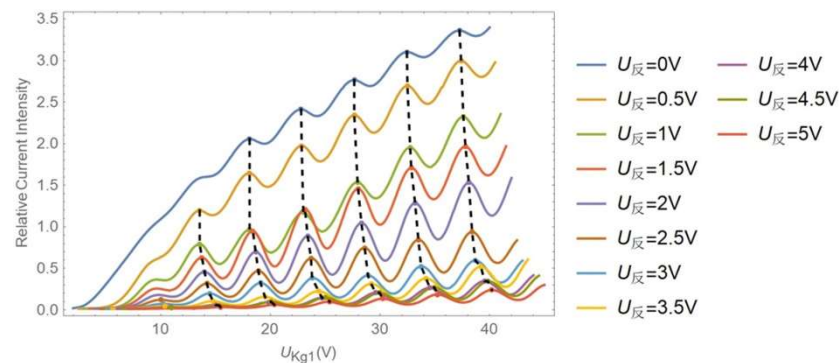
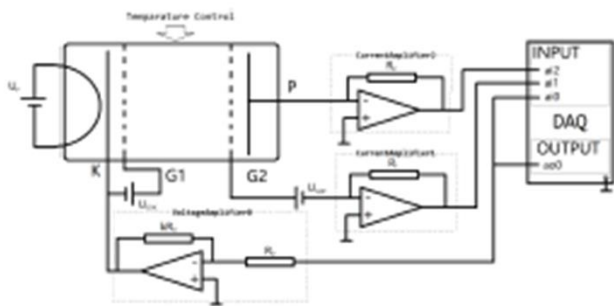


图 3-7 自动化弗兰克-赫兹实验程序框图



举例：基于虚拟仪器技术的弗兰克赫兹实验

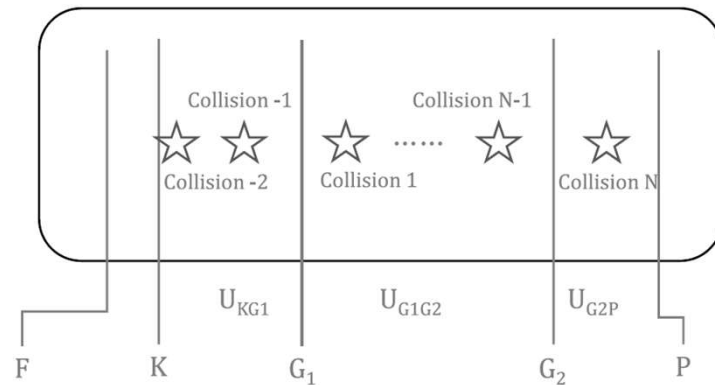
专题研究：自由发挥，题目有很好的开放性、可扩展性

1. 乔天宇，弗兰克-赫兹实验参数分析及蒙特卡洛模拟
2. 王志元，从简单数值模型看Frank-Hertz 实验曲线成因
3. 张文军， Franck-Hertz实验Hg的高激发态测量和参数扫描
4. 孟凡强，测量汞的电离能初探
5. 张一啸，F-H 实验中栅极电流研究
6. 王泓杰，弗兰克-赫兹实验中的反向电流探究
7. 陈颖天，Modeling and Simulation of Franck-Hertz Experiment
8. 翟翀昊，Franck-Hertz实验曲线形状的探究及相关讨论
9. 叶子凌锋，虚拟仪器与弗兰克赫兹实验
10. 黄励勤，弗兰克-赫兹实验
11. 李一一，弗兰克赫兹实验中各参数对峰值位置的影响
12. 朱倩泽，Monte Carlo Simulation of Franck-Hertz Experiment

举例：基于虚拟仪器技术的弗兰克赫兹实验

陈颖天, Modeling and Simulation of Franck-Hertz Experiment

Building Model: Collisions



Building Model: Flow Diagram of an Electron

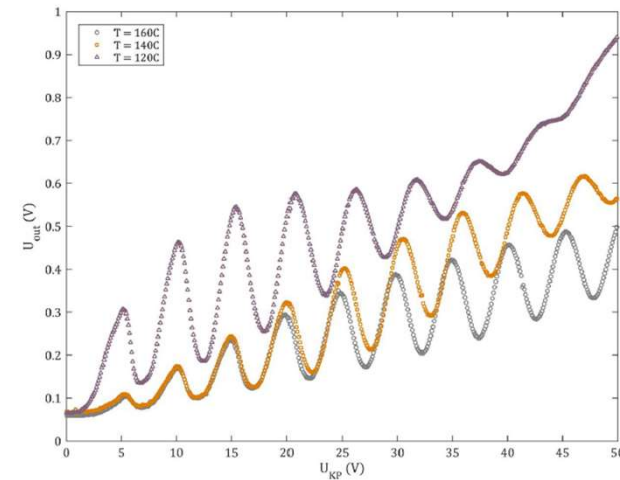
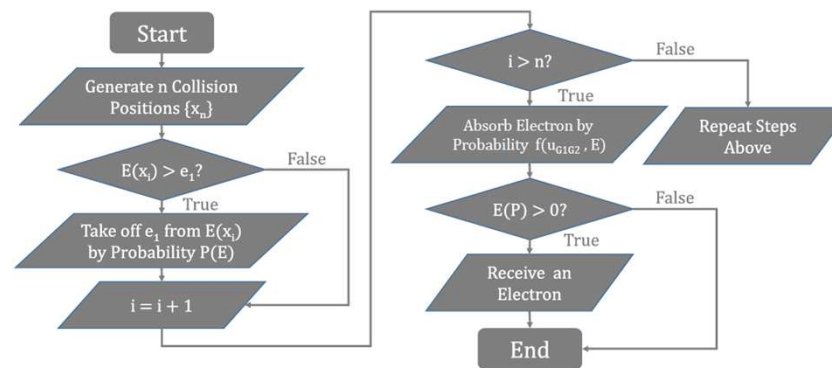


Fig.7(b) Experiment results. $U_{G2P} = 2.5\text{V}$, $U_{KG1} = 3.00\text{V}$, $U_F = 2.0\text{V}$, $T = 160, 140, 120$ (C)

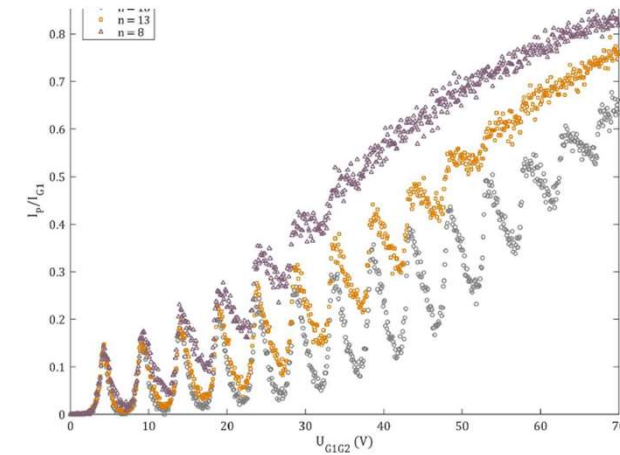


Fig.7(a) Monte-Carlo solution. $n = 18, 13, 8$, $U_{G2P} = 4\text{V}$, $e_1 = 4.89\text{V}$, $P_1 = 0.5$; Repeats = 1000, $\lambda = 2\text{V}$

综合普物实验

传统 + 创新

- 相对固定的题目
- 必要的基本内容
- 固定的上课时间



保障基本质量

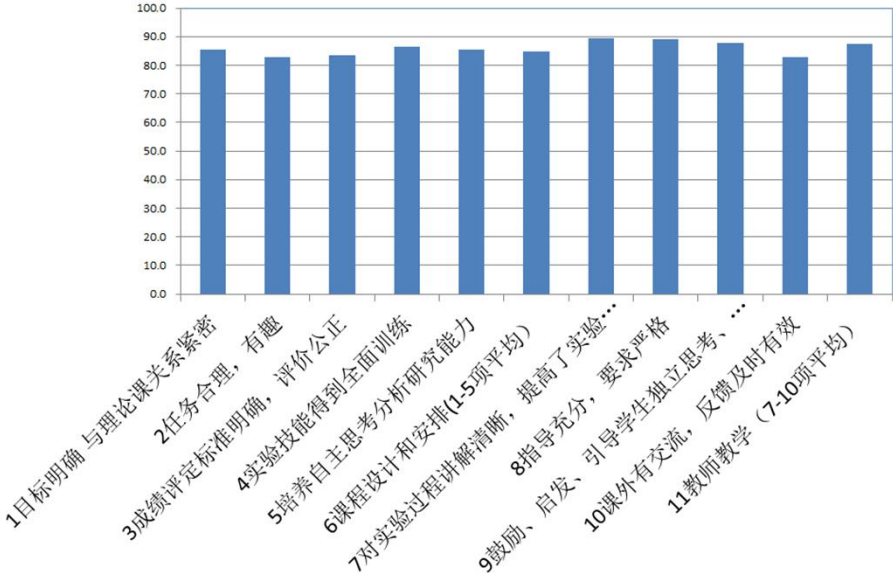
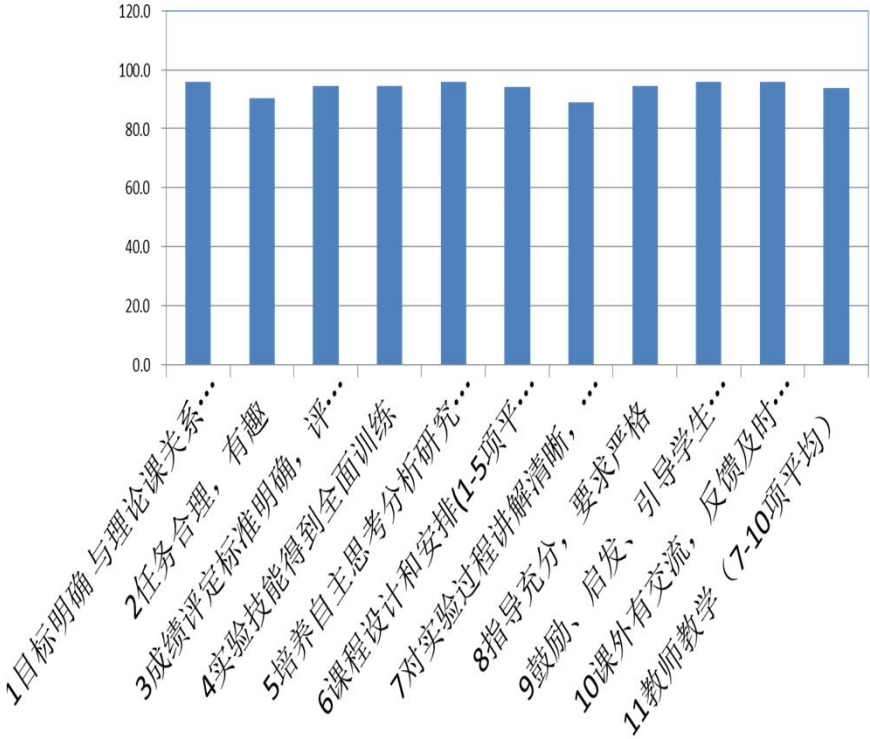
- 完全自主探究：充分训练
- 课后自由加做：主动学习
- 同学相互讨论：沟通合作
- 师生深入交流：加深理解
- 选择专题研究：探索创新
- 口头学术报告：口头表达
- 书面学术论文：书面表达



系统科研训练，培养科研能力

综合普物实验成效：学生评估

问题1-11: (学校评估)	份数	1目标明确与理论课关系紧密	2任务合理,有趣	3成绩评定标准明确,评价公正	4实验技能得到全面训练	5培养自主思考分析研究能力	6课程设计和安排(1-5项平均)	7对实验过程讲解清晰,提高了实验效率	8指导充分,要求严格	9鼓励、启发、引导学生独立思考、勇于探索、大胆质疑	10课外有交流,反馈及时有效	11教师教学(7-10项平均)	总平均分
18春	综物18	95.8	90.3	94.4	94.4	95.8	94.2	88.9	94.4	95.8	95.8	93.8	94.0
	传统203	84.0	81.0	80.2	85.5	84.5	83.0	87.6	87.6	85.8	80.9	85.5	84.1
19春	综物24	89.6	82.3	91.7	85.4	95.8	89.0	84.4	90.6	95.8	92.7	90.9	89.8
	传统175	87.7	84.0	80.5	86.9	85.5	84.9	88.9	88.4	87.8	80.4	86.4	85.6



问题16. 学生对课程感想、体会、意见和建议

*几个实验都很有趣，也都很有挑战性，但是每个实验两周，对于一些有趣的问题，时间不足以深入。。。*其他同学过于优秀导致自己压力很大，不太希望与他们同台竞争。。。*任务量相对较大，但的确得到很多提升，探索过程也使人觉得充实。。。*希望能设计更多新的实验，涉及更多前沿领域。。。*任务量有点大？但是收获和付出成正比。。。*由于课程进行过程中需要较多的自主思考与探索，因而确实遇到许多困难，但不断解决问题的过程中也让我成长了许多。。。*觉得自己的能力有一些难以驾驭，对理论的理解和实验的操作都不如其他同学，但还是有许多收获。。。*感谢各位老师，每位老师都非常耐心地讲解并给出意见和建议，在本学期的实验中，我的各项能力都得到了提高。。。*综物实验让我经受了不少锻炼，此处难一一写出，就让它留在我心中。。。

问题12: 收获最大的实验	光	迈	虚	镊	弦	斑
2018春	8	7	6	2	8	10
2019春	6	10	8	9	8	10

问题13: 仪器	份数	a. 非常满意	b. 满意	c. 基本满意	d. 不满意
2018春	18	50%	22%	28%	0%
2019春	23	21%	58%	17%	4%

问题14: 投入时间	份数	每周投入时间	份数	普物每周投入时间
2018春	18	12.1	17	7.8
2019春	24	11.2	24	8.2

问题15: 与传统普物比较	份数	a.远好于传统课程	b.好于传统课程	c.差不多	d.不如传统课程	e.远不如传统课程
2018春	18	44%	56%	0%	0%	0%
2019春	24	13%	74%	13%	0%	0%

综合普物实验成效：实验竞赛



李一一：基础A，一等奖，第2名



李普天：基础B，一等奖，第2名

第五届全国大学生物理实验竞赛，2019年7月，南开大学

前沿物理实验课程简介

(1)

"前沿

前沿物理实验：学生参与科研的研究性课题实验

历时一个学期，3个学分，供“近代物理实验I”成绩优秀的学生选修。选修此课程的学生每周投入课程的时间不

间不

此课

国际

工作

以国际高水平的研究文献为教材，想方设法重复选定文献的实验内容，完成验证性的实验工作，并对所验证的工作进行综合性的评述，以此引导学生学习前沿科学研究最新的实验成果、科学思想、研究方法与实验技术。

在此基础上，鼓励学生与指导教员紧密合作，争取做出创新性的研究成果。

(2) 选课要求

“近

学生，

择此

“近代物理实验I”的课程成绩为87以上，其中实验笔记得分在13分以上，且有一个实验成绩在90分以上的学生，方可选择本课程。

同意后生效。

(3) 教学要求

每个

学生

(1)

(4)

和末

指导教员应在以下几个环节全程指导学生的研究工作：（1）精读文献，设计重复实验的方案；（2）实施所设计的实验方案；（3）总结、评述，发现新的科学问题；（4）深化实验，争取创新性成果；（5）完成课题研究的书面和口头报告。

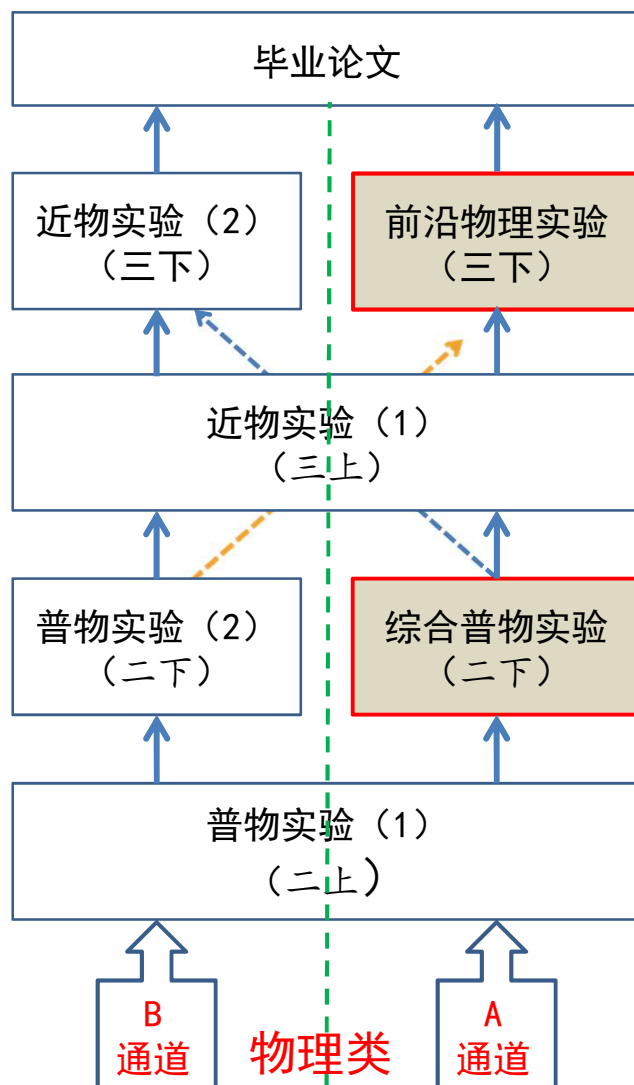
课程的最终成绩由教师评价、实验笔记、口头汇报和研究报告四部分综合评定。

四、总结

优化中的北大物理实验课程体系

主干课程
普通物理实验
近代物理实验

加强基础
循序渐进



教改课程
综合普物实验
前沿物理实验

因材施教
全面提高

感谢各位的聆听！