

# UK Nuclear Physics Graduate School

Status/update

Warwick Meeting  
January 2019

# A Review of UK Nuclear Physics Research

- Review of UK Nuclear Physics Research
- Panel chaired by Professor W. Gelletly
- Report in October 2012
- Made several recommendations...

## 2

The panel recommends that all of the UK academic nuclear physics groups join to form a UK COE in nuclear physics.

- The panel recommends that the initial and formal aspects of PhD education and training are carried out on a UK-wide basis under the auspices of the COE.
- The panel recommends that the COE ensures that publicity/communications about nuclear physics are effective and that the COE and all of the component UK groups in nuclear physics are proactive in publicising nuclear physics in general.
- The panel recommends that the COE acts as a “one-stop” shop to provide a focal point for interaction with potential users of the skills of the nuclear physics community.
- The panel recommends that the COE plays an active role, in partnership with the STFC and EPSRC, in ensuring that the recommendations of the EPSRC/STFC review, particularly recommendations 6–10 in its report, are implemented.

## A brief history of the Graduate School

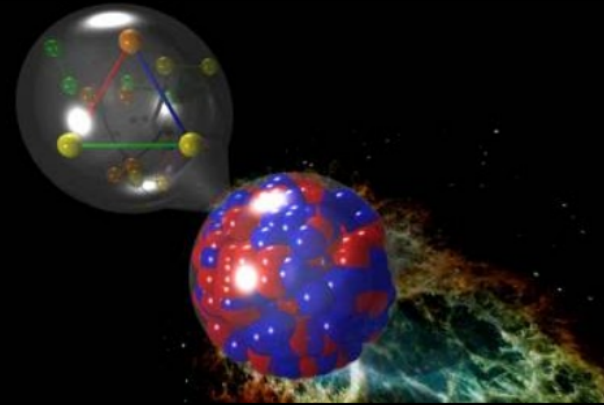
- Graduate School "pilot" put together in summer 2013 by JFS and Jon Billowes.
- 8 modules offered from different institutions
- Different delivery methods
- Operated in AY 2013-2014 and AY 2014-2015, successfully
- Operated in AY 2015-2016, less successfully
- Did not run in AY 2016-2017
- Impetus partly from STFC PhD Studentship Accreditation
- Resumed and refreshed in autumn AY 2017-2018 with input from Alison Bruce and Sean Freeman
- 6 modules offered
- Website: <http://uknuclearphysicsgraduateschool.com>
- Uses free platforms: Google Sites, Google Drive, EventBrite
- Module admin now mostly in the hands of the lecturers
- Anyone can enrol (no restrictions)

## Nuclear Physics Graduate School

Welcome to the web pages the Nuclear Physics Graduate School. The Graduate School is a collaborative effort between all of the UK nuclear-physics research groups, offering specialist PhD-level modules for the education and training of PhD students in nuclear physics.

The collaboration includes the universities of Birmingham, Brighton, Derby, Edinburgh, Glasgow, Liverpool, Manchester, Surrey, UWS, and York, as well as STFC Daresbury Laboratory.

The portfolio of Modules presently available is listed on these web pages in the Modules section. It is expected that other modules will be added as the School develops. So please check the pages regularly to find out what modules are on offer.



## Contacts

The following people are your local contacts for the Nuclear Physics Graduate School.

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If any changes are required to this list, contact your local Editor or [John.F.Smith@uws.ac.uk](mailto:John.F.Smith@uws.ac.uk).

## Modules

### **NPGS001**

#### **Angular Momentum and Gamma Decay**

Dr Paul Campbell (University of Manchester)

*Distance Learning*

[Information](#)

[Register](#)

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### **NPGS005**

#### **Quarks and Hadron Spectroscopy**

Dr Bryan McKinnon & Dr Derek Glazier (University of Glasgow)

*Delivered by video conferencing (part of SUPA Graduate School)*

[Information](#)

[Register](#)

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### **NPGS006**

#### **Nuclear Instrumentation**

Dr Andrew Boston (University of Liverpool)

*Delivered at the University of Liverpool*

Files

Name ↑

**Transition Matrix Elements and The Golden Rule**

1. Expansion of the plane wave

$$\psi_{\mathbf{k}}(\mathbf{r}) = \frac{1}{\sqrt{V}} \sum_{\mathbf{r}'} e^{i\mathbf{k} \cdot \mathbf{r}'} \psi_{\mathbf{k}}(\mathbf{r}')$$

where  $\mathbf{r} = 0$  is the origin, origin is zero and  $\mathbf{r} = \mathbf{r}'$  for particular.

2. Classical Hamiltonian for system plus field

$$H = H_0 + H_1$$

$$H_0 = \frac{p^2}{2m} + V(\mathbf{r})$$

$$H_1 = -\frac{e}{mc} \mathbf{A}(\mathbf{r}, t) \cdot \mathbf{p} + \frac{e^2}{2mc^2} \mathbf{A}(\mathbf{r}, t)^2$$

3. Substituting solutions of the wave equation

$$\nabla^2 \mathbf{A}(\mathbf{r}, t) = -\frac{1}{c^2} \frac{\partial^2 \mathbf{J}(\mathbf{r}, t)}{\partial t^2}$$

$$\mathbf{A}(\mathbf{r}, t) = \int \frac{d^3r'}{4\pi r'} \frac{\mathbf{J}(\mathbf{r}', t - r/c)}{r'}$$

4. Using multipole approximation

$$\mathbf{A}(\mathbf{r}, t) \approx \frac{\mu_0}{4\pi r} \dot{\mathbf{J}}(\mathbf{r}, t)$$

**PDF All\_notes.pdf**

**Angular Momentum and Gamma Decay**

**Final Comment**

A series of 16 lectures from the University of Manchester perspective models, "Elementary Electrodynamics and Quantum Mechanics", with the focus on the quantum mechanical conditions for gamma decay. The material is relevant to particle of nuclear physics systems as well, in the quantum mechanical conditions for gamma decay. The material is relevant to particle of nuclear physics systems as well, in the quantum mechanical conditions for gamma decay.

The first 16 lectures are accompanied by Problem Sheets that are designed to aid your understanding under their own supervision and performance on the course. Each lecture is available in both an audio video format and follows the lecture notes provided.

**Course:** 16 lectures (video format)

**Assessment:** 16 weekly assessed problem sheets.

**Recommended text:** Angular Momentum by Frank D. M. S. Taylor, Angular Momentum by Thompson '91

**Notes:** To provide a focus in the quantum mechanical conditions for gamma decay, analysis of gamma systems and the distribution of angular momentum amongst particles observed during transitions.

**PDF Outline.pdf**

**Angular Momentum Week 1**

1. Multiplication of matrices

Given the matrices

$$T = \begin{pmatrix} 4 & 4 \\ 4 & 4 \end{pmatrix} \quad M = \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$$

evaluate for both cases:

- the eigenvalues,
- the eigenvectors,
- the matrix  $T^2$  when

$T$  or  $M = PDP^{-1}$  and  $P$  is the appropriate diagonal matrix.

By substituting the eigenvalues you will have solved the problem setting from, for example  $T^2$  or  $M^2$  or  $(T^2)^{-1}$  or  $(M^2)^{-1}$ . This problem is based on the characteristic polynomial of the matrix. The Cayley-Hamilton theorem states that the matrix itself satisfies its characteristic, i.e.  $P(T) = 0$  or  $P(M) = 0$ .

4) To identify multiplying out the matrices confirms the result of the Cayley-Hamilton theorem for matrix  $T$  and  $M$ .

Conclude that the characteristic of the matrix  $T$  when multiplied by  $T^2$  gives the

**PDF week1.pdf**

**Angular Momentum Week 2**

1. General angular momentum operators

Given the general set of operators  $J_i$ , where  $i = x, y, z$ , and

$$[J_i, J_j] = i\hbar \epsilon_{ijk} J_k \quad [J_i, J_i] = 0 \quad [J_i, J_j] = 0 \quad [J_i, J_k] = 0$$

where  $J^2 = J_x^2 + J_y^2 + J_z^2$ . Evaluate, by substitution of the above, the following commutators and the factors:

- $[J^2, J_i]$
- $[J^2, J_x]$
- $[J^2, J_y]$
- $[J^2, J_z]$

2. Clebsch-Gordan Coefficients

From a set of Clebsch-Gordan Coefficients for  $J = 3/2$  Rank derived the general expression for a Clebsch-Gordan coefficient:

$$\langle J_1, M_1; J_2, M_2 | J, M \rangle = \frac{1}{\sqrt{2J+1}} \sqrt{\frac{(2J+1)!}{(J_1+J_2+J)!}} \sqrt{\frac{(J_1+J_2-J)!}{(J_1+J_2+J)!}} \sqrt{\frac{(J_1+M_1)! (J_2+M_2)! (J-M)!}{(J_1-M_1)! (J_2-M_2)! (J+M)!}}$$

**PDF week2.pdf**

**Angular Momentum Week 3**

1. Coupling of 2 angular momenta

Two particles from the same shell can only couple to form a  $J$  state if the individual angular momentum quantum numbers  $l_1, l_2$  coupling, respectively, the total angular momentum quantum number  $l$  is equal to the sum of  $l_1$  and  $l_2$  or the absolute value of the difference of  $l_1$  and  $l_2$ . Coupling to directly coupled to other values, the  $(l_1, m_1)$  and  $(l_2, m_2)$  configurations must form  $J$  states.

In a  $2l$  coupling representation the particles from the same shell can only couple to form  $2l$  and  $0$  states, with the  $0$  being the only  $J=0$  state.

Example:  $l_1 = 1, l_2 = 1$

$$J = l_1 + l_2 = 2, 1, 0$$

2. Racah's formula

Explicitly evaluate:

$$\langle l_1, m_1; l_2, m_2 | J, M \rangle = \frac{1}{\sqrt{2J+1}} \sqrt{\frac{(2J+1)!}{(J_1+J_2+J)!}} \sqrt{\frac{(J_1+J_2-J)!}{(J_1+J_2+J)!}} \sqrt{\frac{(J_1+M_1)! (J_2+M_2)! (J-M)!}{(J_1-M_1)! (J_2-M_2)! (J+M)!}}$$

By substituting the factor expansion, evaluate:

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**Angular Momentum Week 4**

1. Racah's formula

Evaluate the  $3j$  symbol of the  $6j$  symbol reduced matrix elements for  $J = 1$ , in  $(1, 0; 1, 0) | 1, 0 \rangle$  and  $(1, 0; 1, 0) | 1, 0 \rangle$ .

in the following cases:

- Firstly describe the  $6j$  symbol in terms of  $3j$  symbols (use the fact that  $3j = 3j$  and drop the 3 in the definition)
- Relate the  $6j$  symbol to the  $3j$  symbols and a Racah coefficient  $W(l_1, l_2, l_3, l_4; l_5, l_6)$  where the integer is greater than 6.
- Repeat  $W(l_1, l_2, l_3, l_4; l_5, l_6)$  in terms of  $3j$  symbols (use the results of 1), identify the  $3j$  symbols of  $3j$  or  $6j$  form. Show the answer can be written as  $W(l_1, l_2, l_3, l_4; l_5, l_6) = \frac{1}{\sqrt{2J+1}} \sqrt{\frac{(2J+1)!}{(J_1+J_2+J)!}} \sqrt{\frac{(J_1+J_2-J)!}{(J_1+J_2+J)!}} \sqrt{\frac{(J_1+M_1)! (J_2+M_2)! (J-M)!}{(J_1-M_1)! (J_2-M_2)! (J+M)!}}$
- Use the  $3j$  and  $6j$  symbols derived earlier to evaluate  $W(l_1, l_2, l_3, l_4; l_5, l_6)$  and show that the required matrix elements:

2. Coupling of 3 momenta

For the coupling result derived in the lecture and tabulated or computed Clebsch-Gordan coefficients to evaluate the above matrix elements from the coupling of two  $2j$  states.

**PDF week4.pdf**

3. Clebsch expansion for 3 momenta

From the required coupling of two  $2j$  states it is possible to show (in tensor notation) that the Clebsch-Gordan coefficients for a spin  $1$  particle are given by:

where  $\mathbf{r}$  is the unit vector in the  $\mathbf{z}$  direction.

By inspection of the general formula conclude that:

$$\langle 1, 0 | \mathbf{r} | 1, 0 \rangle = \frac{1}{\sqrt{2}}$$

This enables the calculation  $\langle 1, 0 | \mathbf{r} | 1, 0 \rangle = \frac{1}{\sqrt{2}}$  and confirm:

$$\langle 1, 0 | \mathbf{r} | 1, 0 \rangle = \frac{1}{\sqrt{2}}$$

and confirm:

$$\langle 1, 0 | \mathbf{r} | 1, 0 \rangle = \frac{1}{\sqrt{2}}$$

which is a critical result for angular distribution theory as it allows us to prove  $\langle 1, 0 | \mathbf{r} | 1, 0 \rangle = \frac{1}{\sqrt{2}}$  as proportional to a series of Legendre polynomials.

Now evaluate the calculation  $\langle 1, 0 | \mathbf{r} | 1, 0 \rangle = \frac{1}{\sqrt{2}}$  and check that the result is correct.

**PDF week4ext.pdf**

**Angular Momentum Week 5**

1. Electromagnetic transition

A key consideration in the calculation of a transition rate is the square of a matrix element of the transition operator  $T_{fi}$  in a multipole expansion of spherical tensor that describes the transition between two states.

The strength of an electric dipole transition induced by plane polarized light, the relative probability  $P_{fi}$  of transition from one multipole angular momentum state to another in a different angular momentum state is given by:

$$P_{fi} = \frac{1}{2J_i+1} \frac{1}{2J_f+1} \frac{1}{2J_i+1} \frac{1}{2J_f+1} \frac{1}{2J_i+1} \frac{1}{2J_f+1}$$

where  $J_i$  is the initial angular momentum of the system and  $J_f$  is the final angular momentum of the system (the vector sum of  $J_i$  and  $J_f$  is  $J$  respectively).

Application of the Wigner-Eckart theorem gives:

$$P_{fi} = \frac{1}{2J_i+1} \frac{1}{2J_f+1} \frac{1}{2J_i+1} \frac{1}{2J_f+1} \frac{1}{2J_i+1} \frac{1}{2J_f+1}$$

4) By inspection of the Clebsch-Gordan coefficients derive the  $6j$  and  $9j$  symbols which are also tabulated Clebsch-Gordan.

The 'reduced' matrix element in equation (1) can be further reduced in the event  $l_1$  is a member of a special class of angular coupling problems. In our problem an electron and neutron can couple to form a series of total angular momentum  $J$  and from the

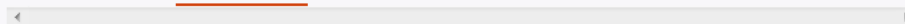
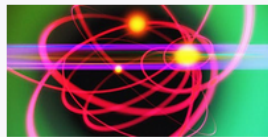
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# Nuclear Physics Graduate School



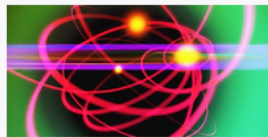
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Past Events 6




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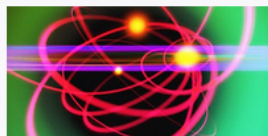
SAT, 1 SEP 09:00  
**Modern Modelling and Computation in Nuclear Structure**  
Department of Physics, Heslington

FREE #ScienceTech  
  - 



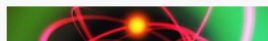
MON, 9 JUL 13:00  
**Nuclear Instrumentation**  
Oliver Lodge Laboratory, Liverpool

FREE #ScienceTech  
  - 

MON, 18 JUN 09:00  
**Hands-on Experiments at the Birmingham Cyclotron**  
School of Physics and Astronomy, Birmingham

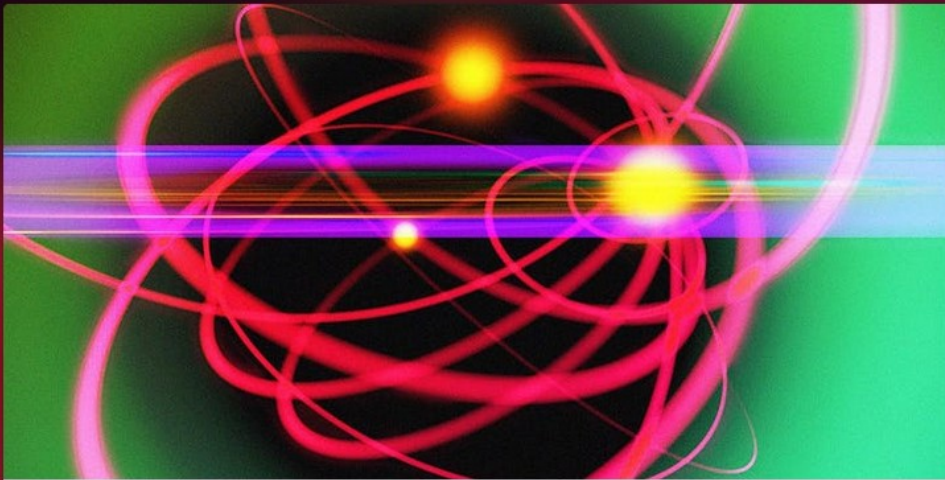
FREE #ScienceTech  
  - 

WED, 18 APR 13:30  
**Nuclear Reaction Theory**  
Department of Physics, Guildford

FREE #ScienceTech  
  - 

WED, 11 APR 09:00





DEC  
04

## Angular Momentum and Gamma Decay

by Nuclear Physics Graduate School

Free



Sales Ended

Details

### Description

Dr Paul Campbell  
University of Manchester

Delivered by distance learning  
(video lectures and PDF lecture notes).

Normally delivered in November/December.

### Tags

Things To Do In Manchester

Other

Science & Tech

### Date And Time

Mon, 4 Dec 2017, 09:00 –  
Fri, 30 Mar 2018, 09:00 GMT  
[Add to Calendar](#)

### Location

Schuster Building  
School of Physics and Astronomy  
University of Manchester  
Manchester  
M13  
[View Map](#)

## Modules offered in AY 2017-2018

<i>Title</i>	<i>Lecturer</i>	<i>Institution</i>	<i>Date</i>	<i>Delivery</i>	<i>Enrollments</i>
Modelling and Computation in Nuclear Structure	Pastore	York	01/10/2018	Face-to-face	3
Nuclear Instrumentation	Boston	Liverpool	09/07/2018	Face-to-face	10
Hands-on Experiments at the Birmingham Cyclotron	Wheldon	Birmingham	18/06/2018	Face-to-face	10
Nuclear Reaction Theory	Timofeyuk	Surrey	18/04/2018	Face-to-face	15
Quarks and Hadron Spectroscopy	McKinnon	Glasgow	11/04/2018	Video conferencing	5
Angular Momentum and Gamma Decay	Campbell	Manchester	04/12/2017	Blended	5

### Defunct modules

Nuclear Models (Paul; Liverpool)

Nuclear Astrophysics (Aliotta; Edinburgh)

Hands-on Shell Model (Simpson; UWS)

## My opinions

- It is not perfect but it is working OK
- It is worthwhile and should continue
- As it stands, it is as good as it can get
- Based on goodwill and community spirit
- We can make small changes...
  - Request more modules
  - Encourage students to enrol
  - Better feedback
  - Annual meeting of lecturers or reps (at Forum?)
- For bigger improvements need commitment, predefined timetable, assessment, QA etc
- Needs complete buy-in from community and incentive for lecturers and institutions

## Points for discussion

- Should we continue in the same manner?
- Should we ask STFC for funding for administration, student travel and subsistence etc?
- Which modules are missing (e.g. nuclear astrophysics)?
- Should we have a list of core modules?
- Should the modules run on a two-year cycle?
- What are the incentives for the lecturers/institutions?
- Should it be made more formal?
- Assessment and quality assurance?
- Should it have better integration with the summer school?
- Can it be used for training for Global Challenges proposals?