Nuclear Science: Teacher Resources

The intention of the following resources is to provide secondary and sixth form science teachers with materials to enrich their classes and inspire the students. A secondary, but no less important aim, is to help teachers themselves brush up on their science knowledge and keep the spark alive for them too.

Useful websites

- National Nuclear Data Centre chart of nuclides: www.nndc.bnl.gov/chart/
    - The chart of nuclides is how nuclear scientists arrange all the isotopes, much like a nuclear version of the periodic table. The number of protons an isotope has runs up the y-axis and the number of neutrons runs along the x-axis so that each row is one element.
    - Website is run by Brookhaven National Laboratory in America. Click on an isotope or use the search box on the right hand side to find an isotope. For example, to find americium 241 (used in smoke alarms), type Am241 in the box and press enter. At the bottom of the screen a table will appear with basic information such as half life and decay modes (what it usually emits). Clicking on "Decay Radiation" will give more detail about decay modes.
- Dynamic periodic table: www.ptable.com/
    - Pretty user friendly website with loads of information. Explore the tabs at the top to make something different happen when you click on an element. For example, clicking the "Isotope" tab will make all the isotopes of an element appear when selected.
- TRIUMF educational videos: www.triumf.ca/home/visiting-triumf/for-students-teachers#PIA
    - TRIUMF is Canada's national lab for nuclear and particle physics. There are various resources on this page, although some will be more suitable to A-level students. I think the second video in the Physics in Action video series would be good for gifted GCSE students.
- Science Saturday resources: www.orau.org/science-saturdays/resources.html
    - Oak Ridge National Lab used to sponsor free science activities for students on Saturday. They have been put on an indefinite hiatus due to budget cuts but the resources from when it was running are still available.
- Science in school: www.scienceinschool.org/
    - Sponsored by the ESRF, this online journal features resources for all areas of science and is available in a large selection of languages.

- Feynmann Lectures are available to read here: www.feynmanlectures.info/. The website also has a selection of exercises with answers for more advanced students to try. Many of his lectures are also available to watch on YouTube. There are many videos of him talking about various things collated on this website: www.feynmanphysicslectures.com/ If you haven't watched him explain physics concepts before then I would reccommend it. He was one of the great scientific minds of our time, and a wonderful orator.
- PhD Comics have made some videos which discuss nuclear physics concepts. Try these:
    - Where do we come from? phdcomics.com/tv/#064
    - The Fingerprint of Stars phdcomics.com/tv/#020
    - What is fusion? phdcomics.com/tv/#061
- The Institute of Physics (IOP) magazine, PhysicsWorld, has a series of 100 second science videos. Give them a try: physicsworld.com/cws/Landing/100secondscience.do
- The IOP also has resources for teaching science topics and support for teachers: http://www.iop.org/education/teacher/index.html
- Learn Physics youtube channel: www.youtube.com/channel/UCjoUaA_fquSXRWBitCJZG9g has lots of GCSE level revision videos. I have used the nuclear physics revision video for the crossword activity included in this pack.
- James Webb Space Telescope: www.jwst.nasa.gov/
    - Joint funded by NASA and the ESA (European Space Agency), this telescope is due to be launched into space next year.
    - The website has webcams of the work going on building and testing the telescope as well as suggested activities, lesson plans and other resources.
- Space:uk magazine: www.gov.uk/government/publications/space-sector-magazine-spaceuk
    - The magazine published by the UK space agency.
    - PDFs available online.
- European Space Agency: www.esa.int/ESA
    - INformation about current projects and missions, bios of astronauts, information on careers with the ESA, videos and amazing photos!
- The Science and Technology Facilities Council website has lots of useful information www.stfc.ac.uk . They offer work experience placements for yr 10,11 and 12 here: www.stfc.ac.uk/1348

Nuclear research facilities around the world (a selection)

The first thing you'll notice upon scanning through this list, is that I have not included a nuclear research facility in the UK. This is because unfortunately the UK does not have such a facility at the moment. We do have labs which focus on other areas of physics and a fusion research facility (JET http://www.ccfe.ac.uk/) but this is only a small aspect of nuclear physics research as a whole. The universities most involved in nuclear physics research in the UK are the University of Liverpool, York University and Surrey University.

The majority of experimental physics research has to be done at a large laboratory facility so being a nuclear physicist means a fair amount of travel and networking is very important in order to learn who is doing what work and whether there are collaboration opportunities to be had!

Pretty much all of the facilities on this list offer opportunities for physics undergraduate students to go work there for a summer, certainly something to aspire to!

North America

Name: TRIUMF, Canada's national laboratory for nuclear and particle physics
Location: Vancouver, BC, Canada
Number of employees: There are about 340 staff employed at TRIUMF; in addition, about 150 other visitors, students, and researchers work at TRIUMF each day. Every year there are about 500 scientific visitors who come to TRIUMF for short periods of time to conduct experiments or research during the year.
Size of Facility: The TRIUMF site is 0.02 square miles (12.55 acres).
Infrastructure: World's largest cyclotron which produces proton beams. TRIUMF has 4 beamlines and produces rare isotope beams for use at various experimental stations around the facility.
Types of research:

- Rare-Isotope Beams
- Particle Physics
- Nuclear Medicine
- Molecular and Materials Science
- Accelerator Physics
- Particle and Nuclear Physics Theory

- Detector Development

Notes: TRIUMF stands for TRI-University Meson Facility as it was initially funded by 3 universities and was intended for just meson research.
Website: http://www.triumf.ca/
Can I get a tour? Yes! Tours run daily and are free of charge.

Name: Oak Ridge National Laboratory (ORNL)
Location: Oak Ridge, Tennessee, USA
Number of employees: 4480 in total, 2600 scientists plus 3000 scientists who visit for experiments.
Size of Facility: 58 square miles (37120 acres)!
Infrastructure: Oak Ridge National Laboratory is the largest science and energy national laboratory in the Department of Energy system. ORNL homes several of the world's top supercomputers as well as a nuclear reactor for isotope production and a high power neutron source.
Types of research:

- Materials - Center for Nanophase Materials Sciences, High Temperature Materials Laboratory
- Neutron science - High Flux Isotope Reactor and the Spallation Neutron Source
- Energy
- High-performance computing - National Center for Computational Sciences
- Systems biology - Center for Structural Molecular Biology
- National security
- National Transportation Research Center

Notes: ORNL was HQ for the Manhattan project during WWII but has had no participation is the production of nuclear bombs since the end of the war.
Website: http://www.ornl.gov/
Can I get a tour? Yes! But you have to register at least 2 weeks in advance.

Name: Brookhaven National Laboratory
Location: Long Island, New York, USA
Number of employees: 3000
Size of Facility: 8.1 square miles (5265 acres)
Infrastructure:

- Relativistic Heavy Ion Collider
- Center for Functional Nanomaterials

- National Synchrotron Light Source II
- NASA Space Radiation Facility
- Accelerator Test Facility
- Computational Science Center
- Brookhaven Linac Isotope Producer

Types of research:

- Energy Security: Blazing innovative trails toward a sustainable future powered by solar, wind, hydrogen, and other renewable sources.
- Photon Sciences: Focusing ultra-bright light to reveal the structures of materials critically important to biology, technology, and more.
- QCD Matter: Colliding subatomic particles to recreate matter from the dawn of time, and study the force that gives shape to visible matter in the universe today.
- Physics of the Universe: Exploring cosmic mysteries across the smallest and largest scales imaginable, from neutrinos to dark energy.
- Climate, Environment, & Biosciences: Mapping climate change, greenhouse gas emissions, and plant biology to protect our planet's future.

Notes: BNL run various educational programs which students can attend for a fee. BNL may have created the first video game, it was designed to entertain visitors http://www.bnl.gov/about/history/firstvideo.php
Website: http://www.bnl.gov/world/
Can I get a tour? Yes! But you must make a reservation 3 weeks in advance. Tours are run for groups of 10 or more and are available Mon-Fri between 9am and 3pm.

Other labs in the USA include:

- Lawrence Livermore National Laboratory, Livermore, California, USA. https://www.llnl.gov/
- Lawrence Berkeley National Laboratory, Berkeley, California, USA. http://www.lbl.gov/
- National Superconducting Cyclotron Laboratory (NSCL), East Lansing, Michigan, USA. http://www.nscl.msu.edu/index.php

Europe

Name: Institut Laue-Langevin

Location: Grenoble, France
Number of employees: 497
Infrastructure: Houses the world's most intense neutron source.
Types of research: Neutron science including research into magnetism, materials, biology and chemistry.
Notes: The ILL is right next door to the ESRF (see below) and they share a canteen which includes an espresso bar.
Website: http://www.ill.eu/
Can I get a tour? Yes! But visitors must be 15 or older and tours must be booked in advance. It is possible to combine tours of the ILL with the ESRF.

Name: European Synchrotron Radiation Facility (ESRF)
Location: Grenoble, France
Number of employees: 600 plus up to 3500 visiting scientists a year.
Infrastructure: Most powerful synchrotron radiation source in Europe.
Types of research: Electrons are accelerated in order to produce x-rays which are used in various types of research including biology, materials and magnetism.
Notes: The ESRF is operated and supported by members from 21 countries. The synchrotron has an 844m circumference and the scientists use bicycles to get around it to different experimental stations.
Website: http://www.esrf.eu/
Can I get a tour? Yes! Same as ILL, visitors must be at least 15. Tours must be booked 2 months in advance.

Name: GSI Helmholtz Centre for Heavy Ion Research
Location: Darmstadt, Germany
Number of employees: GSI is one of 18 Helmholtz centres in Germany. Across all the centres there is a total of 35672 employees, of which 12269 are scientists. Plus around 7400 scientists visit the sites to do experiments each year. GSI specifically has 1050 staff.
Infrastructure: The GSI facilities include the 120 metre long linear accelerator UNILAC (Universal-Linear-Accelerator) and the heavy-ion synchrotron (Schwer-Ionen-Synchrotron - SIS) with a diameter of 70 metres which can accelerate ions to extreme speeds through which they take on high energies. These ions then disintegrate into nuclear fragments when they collide with the target. They are subsequently separated by mass and atomic number and collected in a storage ring.
Types of research: The Helmholtz centres cover: Energy, Earth and Environment, Health, Aeronautics, Space and Transport, Key Technologies, plus Structure of Matter. GSI specifically focuses on nuclear and atomic physics as well as work on plasma physics, materials research, biophysics, accelerator development and radiation medicine
Website:

Helmholtz Centres - http://www.helmholtz.de/en
GSI - https://www.gsi.de/en/start/news.htm
Media: Image and video archives for all the Helmholtz centres: http://www.helmholtz.de/en/press/media/images_and_video_archives_of_the_helmholtz_centres/
Can I get a tour? Yes, free of charge. It takes 2 hours and runs Mon-Fri.
What about taking part in the School labs network at one of the Helmholtz centres? Students can do experiments and talk to scientists. A variety of subjects are on offer. See the following website for more details:
www.helmholtz.de/en/jobs_talents/school_labs_network/

Name: Legnaro National Laboratories (LNL)
Location: Legnaro, Italy
Number of employees: More than 800 scientists from around the world are involved in research at LNL with about 250 people working there each day where about half of that are actual LNL employees.
Infrastructure: 5 accelerators and various detector set ups.
Types of research: Nuclear structure, nuclear reaction studies, nuclear fusion, environmental radiation monitoring.
Website: http://www.lnl.infn.it/index.php/en/
Can I get a tour? Yes, there is a registration form to fill in on the website.

Other European facilities:

- CERN (European organisation for nuclear research), Geneva, Switzerland**.** http://home.web.cern.ch/
- JYFL Accelerator Laboratory, Jyväskylä, Finland. https://www.jyu.fi/fysiikka/en/research/accelerator

Africa

Name: iThemba Labs
Location: Cape Town, South Africa
Types of research: Nuclear physics, materials research and radiation biophysics.
Website: http://www.tlabs.ac.za/
Notes: The head of iThemba Labs, Simon Mullins, is originally from the UK and got his BSc from the University of Leicester, his MSc from the University of Bradford and his PhD from the University of York.
Can I get a tour? Yes, you have to book in advance and be over the age of 13.

Russia

Name: Joint Institute for Nuclear Physics
Location: Dubna, Russia
Number of employees: About 5000 employees including 1200 scientists, 2000 engineers and technicians.
Types of research: Theoretical and experimental studies in elementary particle physics, nuclear physics, and condensed matter physics.
Website: http://www.jinr.ru/

Other facilities worth looking into:
Name: Saha Institute of Nuclear Physics
Location: Kolkata, West Bengal, India
Website: http://www.saha.ac.in/web/

Name: RIKEN Nishina Center for Accelerator Science
Location: Hirosawa, Japan
Website: http://www.riken.jp/en/research/labs/rnc/

Crossword Activity

The following information was used to create the crosswords included in this pack. There are 3 versions but they all use the same clues. The crosswords were made using this website: http://worksheets.theteacherscorner.net/make-your-own/crossword/

Complete the crossword using this video for help:

https://www.youtube.com/watch?v=cBP6_55Tykc

Nucleus / You find this in the centre of an atom.

Plum Pudding / Name the model of the atom where the atom is thought of as being a sphere of negative charge with electrons spread through it.

Ernest Rutherford / British scientist who discovered the nucleus.

Alpha / Type of particle used in Rutherford's gold foil experiment.

Electron / Particle that orbits the nucleus.

Neutron / Neutral particle in the nucleus.

Proton / Positively charged particle in the nucleus.

Mass number / Total number of protons and neutrons in the nucleus of an atom.

Isotope / Atom with different number of neutrons.

Eight / Number of protons in oxygen.

Radioisotope / Radioactive isotope.

Radon / Approximately 50% of our background radiation comes from this naturally occurring radioactive gas.

Cosmic Ray / Background radiation from outer space.

Helium / An alpha particle is the same as the nucleus from this element.

Beta / This type of radiation is an electron.

Gamma / This type of radiation is energy.

Fission / Splitting of the nucleus.

Uranium / Element used in nuclear fission power stations.

Barium / An element that could be produced in the fission of uranium.

Fusion / The joining together of nuclei.

Star / Fusion reactor in space.

Day trip ideas

Space
Spaceport in Merseyside: www.spaceport.org.uk
Planetarium at the World Museum, Liverpool:
http://www.liverpoolmuseums.org.uk/wml/visit/floor-plans/planetarium
Jodrell Bank Discovery Centre: www.jodrellbank.net

Nuclear power
http://www.edfenergy.com/energy/education/visitor-centres

Lasers!
Rutherford Appleton Laboratory, home of one of the worlds leading laser facilities: http://www.stfc.ac.uk/76.aspx They have public access days every year more information here: http://www.stfc.ac.uk/2611.aspx

General Science
The Science and Technology Facilities Council have lots of resources for schools and advice on visiting the national labs here: http://www.stfc.ac.uk/1801.aspx
Lots of ideas for school trips here: www.planmyschooltrip.co.uk/science
Advice on organising industry visits from the IOP:
http://www.iop.org/education/higher_education/stem/resources/file_44403.pdf

Current events:

Top physics discoveries of the year:
www.bbc.co.uk/news/science-environment-30415007

Rosetta mission
http://www.esa.int/ESA
http://rosetta.jpl.nasa.gov/
Comet landing game: http://www.bbc.co.uk/news/science-environment-29746430

Hinkley Power Plant and nuclear power in general

- Types of nuclear reactor:
  http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/reactor.html

    - Hyperphysics is not the prettiest website out there but the information is good quality and it is pretty much a bottomless pit of information.
- Information about the plant from the company in charge of building it: www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c
- All things nuclear: http://teachnuclear.ca/contents/
    - This is a Canadian website so it has information on the type of reactors they have there but they also talk about other types as well as loads more information about nuclear physics in general.
- When discussing nuclear power you will inevitably get asked about nuclear waste. It isn't as big a deal as some media may have led us to believe. Here's an article to get you started: 10 cool things about nuclear waste. www.thingsworsethannuclearpower.com/2013/05/10-cool-things-about-nuclear-waste.html
- Article in Scientific American (a magazine similar to New Scientist) written by 3 retired physicists who worked on nuclear reactor development. www.scientificamerican.com/article/smarter-use-of-nuclear-waste/
- Relevant XKCD: http://xkcd.com/1162/

Fusion

The big fusion research project ITER is located in France. It is being funded by a collaboration of countries. www.iter.org/

Radiation Safety

Radiation safety is important to consider in all nuclear science applications. Understand what constitutes safe levels of radiation before making judgements on any nuclear-related topics.

- UK dose limits: www.hse.gov.uk/radiation/ionising/doses/
- Radiation exposure comparison: www.theguardian.com/news/datablog/2011/mar/15/radiation-exposure-levels-guide
- Relevant XKCD: https://xkcd.com/radiation/

Medical Physics

Medical physics is in the news regularly as new techniques become available. The Institute of Physics (IOP) has resources covering a great deal of medical physics topics. For each area covered they include videos, worksheets a presentation and teachers notes.

http://www.iop.org/education/teacher/resources/teaching-medical-physics/page_54690.html

Element 117 and Superheavies

Element 117 was recently discovered. The following articles discuss what its discovery means for nuclear physics:

http://www.scientificamerican.com/article/superheavy-element-117-island-of-stability/

http://physicsworld.com/cws/article/news/2014/may/09/superheavy-element-117-weighs-in-again

The scientific paper reporting its initial discovery in Russia can be found here:

http://albert.cau.free.fr/English/PhysRevLett.104.142502.pdf