Introduction to Junior Lab 8.14 — Spring 2012
Policies, Procedure, and Safety Information

Junior Lab Staff
MIT Department of Physics
(Dated: January 29, 2012)

1. OVERVIEW OF 8.14

The purposes of Junior Lab are to give you hands-on experience with some of the experimental bases of modern physics and, in the process, to deepen your understanding of the relations between experiment and theory, mainly in atomic and nuclear physics. You will do experiments on phenomena whose discoveries led to major advances in physics. The data you obtain will have inevitable systematic and random errors that obscure the relations between the macroscopic observables of our sensory experience and the physical laws that govern the submicroscopic world of atoms and nuclei. You will be challenged to learn how each of the experimental setups works, to master its manipulation so that you obtain the best possible data, and then to interpret the data in light of theory with a quantitative assessment of the errors. We believe you will find satisfaction in observing, measuring and understanding phenomena many of which would have won you the Nobel Prize if you had discovered them.

Students enrolling in 8.14 are expected to have recently completed 8.05 and 8.13 so as to be prepared to immediately begin conducting investigations. If you have not taken 8.13, please see the head Junior Lab instructor.

1.1. Section Organization

The Registrar has preassigned you to one of the sections listed in Table I, with further adjustments reflected on the 8.14 Stellar web page. If you cannot come to the assigned time, please email `spatrick@mit.edu` ahead of time to see if the section of your choice can be accommodated. Attempts are made to keep each section's enrollment less than or equal to 16 students. If the course enrollment is especially large, you may not be able to have the section of your choice.

Each section of Junior Lab is run independently by one faculty member with the assistance of a graduate teaching assistant. *You are required to attend your assigned lab session for the full three hour period. Any exception must be approved by the section teaching staff.* The lab is also open on Fridays from 10AM to 4PM for additional lab time outside of your regularly scheduled section. Friday time reservations (3-hour block maximum, please) can be made through the Junior Lab online reservation tool at http://jlvideo-2.mit.edu/jlab/.

You are expected to work in pairs, sharing as evenly as possible in the measurements, the analysis, and the interpretation of the data. The best choice for a lab partner may be someone who lives nearby and has a schedule that matches yours so you can get together outside of class to analyze and interpret your results. Most students find that they require the full 18 hours per week credited to Junior Lab to do the work of the course.

TABLE I: Junior Lab 8.14 Section Instructors — Spring 2012

Section	Instructor
Monday, Wednesday 1PM–4PM	Professor Paolo Zuccon
Tuesday, Thursday 1PM–4PM	Professor Steve Nahn

1.2. Schedule Summary

The first class period will be dedicated to selecting partners, choosing the first experiment, and brief introductory remarks by the section instructors. The remainder of the term will be divided into four experimental sessions of 5 days each. Experiments for three of the four sessions will be selected from the standard Junior Lab menu, while the fourth will be an open ended project of your own design. (For scheduling reasons, the open ended project will not occur during the first experimental session.)

Before the second experiment begins, each student group will propose a schedule for the use of the remaining three sessions, most notably including the open ended project, the scientific goals of which should be defined in the proposal. A brief draft proposal will be due near the middle of the first experiment, while a more formal two-page written proposal will be due near the end. Proposals should outline the required resources and scheduling constraints for the open ended project. Projects beyond the scope of Junior Lab will be identified and scaled back at the draft proposal stage.

Examples of projects include:

- deeper exploration of a previously performed 8.13 or 8.14 experiment
- performing an experiment still under development by the Junior Lab staff
- assembling and performing a simple Junior Lab style experiment from the American Journal of Physics
- other projects subject to approval

The open ended project will be evaluated based on a written report of similar magnitude to those due on the regular experiments. The student group judged by the 8.14 teaching staff to have proposed and performed the best original project of the year will be awarded the annual Pickering Prize.

Note that the additional fifth day per experiment (beyond what you had in 8.13) raises the level of expectations regarding the completion of "challenging" aspects of the labguides and an expectation to exceed the standard material.

Throughout the term you will be required to keep a detailed laboratory notebook, which is provided to you by Junior Lab. This will be collected and graded 2 times during the semester: once around midterm, and once at the end of the semester.

1.3. Laboratory Access

Beyond your required assigned lab time, the laboratories will be open every class day from 9AM–5PM and Friday from 10AM–4PM (except Institute holidays) with staff help available to discuss physics and maintain equipment. At all other times the laboratories must be kept locked for safety and security, especially the security of radioactive sources. Junior Lab students may occasionally be permitted access to the lab outside of the normal hours, but only after consulting with their TA or faculty member. It is each student's responsibility to maintain security by making sure the doors are kept locked at all times outside of the regularly scheduled sessions. One should never work alone in a laboratory, especially if high voltages are involved. A partner or instructor must be in reach.

2. ETHICS IN SCIENCE AND EDUCATION

When you read the report of a physics experiment in a reputable journal you can generally assume it represents an honest effort by the authors to describe exactly what they observed. You may doubt the interpretation or the theory they create to explain the results but at least you trust that if you repeat the manipulations as described, you will get essentially the same experimental results.

Nature is the ultimate enforcer of truth in science. If subsequent work proves a published measurement is wrong by substantially more than the estimated error limits, credibility is questioned. If fraud is involved, a career may be ruined. Thus, most professional scientists are very careful about the records they maintain (see the Junior Lab notebook requirements in the next section of the reader) and the results they publish.

Junior Lab is designed to provide pre-professional training in the art and science of experimental physics. What you record in your lab book and report in your written and oral presentations must be exactly what you have observed *including date, time and name of experimenter.*

Sometimes you will get things wrong because of an error in manipulation, equipment malfunction, misunderstanding, or a miscalculation. Simply cross out errors using a diagonal line in your notebook and start again. The instructor's job is to help you figure out what went wrong so you can do better next time. If circumstances in an experiment are such that you cannot get your own data (*e.g.* broken equipment, bad weather), you may request your instructor's permission to use someone else's data, provided you acknowledge it.

Fabrication or falsification of data, using the results of another person's work without acknowledgement, and copying from "the files" are intellectual crimes as serious as plagiarism, and possible causes for dismissal from the Institute. This includes using someone else's data without your instructor's explicit permission.

The precaution regarding the acknowledgement of other people's data also applies to acknowledging other people's rhetoric. The appropriate way to incorporate an idea which you have learned from a textbook or other reference is to study the point until you understand it and then put the text aside and state the idea in your own words.

One often sees in a scientific journal, phrases such as "Following Albert Einstein …". This means that the author is following the ideas or logic of Einstein not his exact words. If you quote material, it is not sufficient just to include it in the list of references at the end of your paper. You should use the following formatting:

> The quote should be indented on both sides or enclosed in quotes, and attribution must be given immediately in the form of a reference note.[1]

Importing text from a published work, from other student papers, or from the lab guide without proper attribution is a serious breach of ethics and will be dealt with by the Committee on Discipline.

Most Junior Lab experiments are concerned with data comparison measurements of well known fundamental constants such as $\hbar$, e, k_B, e/m, and c, or significant physical quantities such as the mean life of the muon or the cross section of an electron for scattering a photon. The purpose of these experiments is to give you hands-on experience with atomic and nuclear phenomena, a sense of the reality of the concepts and theories you have studied in books and courses, and the beginning of professional skill in obtaining and recognizing reliable data and extracting meaningful results from them.

There is nothing wrong with "peeking" in the CRC Handbook or any of the many relevant texts to see what

[1] A. Einstein: Personal communication. Footnotes may be placed either at the bottom of the page where referenced or at the end among the bibliography.

your experiment should have yielded. In fact, in your conclusions, you should compare your values with the established ones — as you would in any of your later scientific publications. One way to get maximum benefit from your Junior Lab experience is to play it as a game in which you squeeze the most accurate measurement you can get out of the available equipment and the practical limits of analysis, make a rigorous estimate of the error, and then compare the results with the established value. If the established value is outside your error range, try to find out what went wrong, fix it, and try again. If the established value is in your error range, don't rest easy, but do whatever may be necessary to prove it isn't an accident. Repetition is the essential key to attaining confidence and meaningful errors for a result, whether of a single measurement or an entire experiment! But whatever the outcome of an experiment is, you must tell exactly what you observed or measured when you present your oral or written report, regardless of how "bad" the results may appear to be.

3. REQUIRED TEXTS

- Experimental Lab Guides, available for download from the Junior Lab web site. Lab instructors will be delighted to accommodate your improvements and corrections to the lab guides!
- Data Reduction and Error Analysis for the Physical Sciences, 3rd Edition, by P.R. Bevington and D.K. Robinson (McGraw-Hill: 2003)

The Bevington and Robinson text contains a comprehensive treatment on error analysis and will be useful throughout your career.

3.1. Other Useful Texts

There are several other recommended textbooks on reserve in the Junior Lab library.

- Experiments in Modern Physics by Adrian Melissinos (Academic Press: 1966 1st Edition & 2003 2nd Edition). Please consult these before and during your investigations. This text is only "Recommended" because the Junior Lab staff feel it is too expensive to "Require". *Material which is essential to the understanding of an experiment, and that can be found in the Melissinos text, is generally omitted from the Lab Guides*. Note that the Physics Reading Room has both editions which offer different material, you should consult them both!
- The Art of Experimental Physics by Daryl Preston and Eric Dietz (John Wiley: 1991)
- An Introduction to Error Analysis 2nd Edition, by John Taylor (University Science Books: 1997). This book covers much of the same material as Bevington and Robinson.

3.2. Reference Articles and Equipment Manuals

At this stage of your training as an experimentalist, you should realize that there is no "comprehensive" or perfect textbook. Much of the material you will need to dig into are the early journal papers which originally detailed many of these important discoveries. The Junior Lab website has an electronic library containing many of these articles in PDF format and which is accessible using MIT certificates. Junior Lab also has numerous books on reserve in the Hayden Library Reserve Book Room (14N-132) and the Physics Reading Room (4-332). References and lending book resources are available through Barker and Hayden Libraries and students should become familiar with both of these Institute resources. Finally, there is a small Junior Lab library in 4-361. These books may not by taken from the laboratory, but copies of a few pages may be made on the photocopier.

4. GRADING POLICY

See Table II.

TABLE II: 8.14 grading policy

Attendance and Lab Performance	10%
Laboratory Notebooks (2 checks)	10%
Preparatory Questions (3)	6%
Oral Examinations (3)	27%
4-Page Written Summaries (3)	27%
Project Proposal (2 parts)	11%
Project Report	9 %

4.1. Attendance and Lab Performance — 10%

The regularity of your attendance will be a factor in determining your grade in the course, as will be your preparedness for the measurements and alternating as the "lead" (with your partner), to carry them out.

It is essential that you use efficiently all of the laboratory time assigned to you, and sometimes more. An experienced experimental physicist will be present in every scheduled session. He or she will be assisted by a graduate teaching assistant. In addition, the Junior Lab staff includes technical instructors responsible for the maintenance of the equipment and the development of new experiments. We are ready and eager to help you make things work properly and answer questions. Call for help when you get stuck.

4.2. Laboratory Notebooks — 10%

One critical objective of this course is to instill habits of record keeping that will serve you well in future research. To this end you will be given a standard experimental notebook in which the complete dated record of procedures, events, original data, calculations and results of every experiment is to be kept. **No other form of notebook is acceptable in this course.** Although you will generally work in pairs and are urged to collaborate in all aspects of carrying out the experiments and analysis, each student must keep a complete, dated record of each experiment and its analysis. The grid-lined paper in the notebook is convenient for formatting tabulations, for guiding line drawings, and for making rough plots. High resolution plots, photos, and photocopies of shared data should be glued or taped in place. You must write a sufficient narrative as the experiment proceeds so that, years later, you could reproduce the results you obtained. Notes, tables, and graphs should be neat and compact, leaving as little empty space in the lab notebook as is compatible with clarity and the logic of organization. There should be no loose sheets or graphs in your notebook.

Analyze data in the lab in a preliminary way as you go along to check for reasonableness. If you are making a series of measurements of one quantity as you vary another, plot the results as you go along so that you can see the trend, catch blunders, and judge where you may need more or less data. **Repeat every measurement at least three times in as independent a manner as possible in order to establish a statistical basis for estimating random error and to reduce the chance of blunders.** If you get through all the manipulations and preliminary analysis of an experiment in less than the allotted time, take the opportunity to perfect part or all of the experiment so as to obtain the best possible data set.

Many experiments will require you to transfer your data to a computer and store them in files on disk. Obviously, it is not practical in these cases to print out all your data and paste them into your notebook. However, we expect to see in your lab notebook representative plots or tables. In addition, we expect a clear description and summary of the data files so that when you return to them days or weeks later, you are able to identify particular files with procedures you carried out in the lab.

Specific requirements for your notebooks are listed on the web at Junior Lab notebook guidelines.

Student notebooks will be evaluated twice during the semester. The first check will be around midterm for 3% of the final grade, and the final check will be at the end of the semester for 7% of the final grade. Having already taken 8.13, you should be well versed in how to maintain a good laboratory notebook.

4.3. Preparatory Questions — 6%

Each lab guide has a set of preparatory questions which point you to the essentials of the experiment. You are expected to work out the solutions to the preparatory problems and/or predictions in your notebook before starting the experiment. Make a photocopy of your solutions and deposit it in your TA's mailbox in 4-361. It will be collected shortly after the start of the first session of each new experiment. **Late solutions will not be accepted because you will need to know this material BEFORE the experiment: late solutions do not make sense.** Your solutions will be graded by the graduate teaching assistant and returned at the next session.

4.4. Oral Examinations (3) — 27%

A one hour total length (2 students $\times$ 30 minutes each) oral examination and discussion of each main experiment will be held between the pair of students and one or more of their instructors within 10 days of the last scheduled session for that experiment. Each student must bring his or her lab notebook to the exam session.

Each student should prepare a 15-minute oral report on the theoretical and experimental aspects of a single portion of the experiment. This is a short time, so it is essential that you rehearse your presentation as you would if you were giving a 15-minute presentation at a meeting of the American Physical Society. Please review the Society guidelines at `http://www.aps.org/meetings/policies/speaker.cfm`

We suggest a maximum of ten slides. You must prepare your presentation electronically (*e.g.* LaTeX or `MS PowerPoint`) for use with the LCD projector for the cleanest, most professional presentation possible. The Junior Lab website has detailed instructions and templates for generating your own presentations.

The theoretical section should demonstrate a mastery of some portion of theory relevant to understanding the significance of the experimental results. The experimental section should dominate and demonstrate an understanding of how the equipment works, what was measured, how the data were reduced, and how the random and systematic errors were estimated. **Each student must discuss different aspects of the motivating theory and experiment and furthermore it is not acceptable to discuss theory only or experiment only; every presentation should contain a balance! Full cooperation with lab partners and others in preparing for the oral reports is encouraged.** This latter aspect is particularly important to ensure that both partners report the same results!

Orals will be graded using the following criteria:

- Theoretical and/or experimental motivation: 15%
- Description of experiment: 35%

- Analysis of data and results: 35%
- Style and English: 15%

4.5. 4-Page Written Summaries (3) — 27%

A 4-page written summary must be prepared for each of the three standard experiments.

You must email a PDF copy of your **individually-prepared** written summary ($\leq$4 pages including figures) of the purpose, theory, and results of the experiment to you section instructor by the midnight following your oral examination. It is expected, however, that the paper will essentially complete by the time of your oral exam. The delay between oral exam and paper submission allows you to correct any egregious mistakes that were uncovered during the exam so as not to repeat them in your written work and receive a double penalty!

All your work on the experiment should be summarized, not just the part you chose for your oral presentation. The individual summary you hand in should show evidence of your own mastery of the entire experiment, and possess a neat appearance with concise and correct English. Its organization and style should resemble that of an article in the Physical Review Letters (http://publish.aps.org/STYLE/). **The abstract is essential. It should briefly mention the motivation (purpose), the method (how measured) and most important, the quantitative result WITH uncertainties.** Based on those, a conclusion may be drawn.

The report must be typeset in a form that would be suitable for submission as a manuscript. To aid you in this process we have produced a sample paper template written in LaTeX that we encourage you to study and use for your own submissions. The sample paper is downloadable from the Junior Lab site along with its associated `.tex` file.

The body of the summary should include a discussion of the theoretical issues addressed by the experiment, a description of the apparatus and procedures used, a presentation of the results (including errors!), a discussion of these results, and, finally, a section briefly presenting your conclusions. The total length (including figures) of your summaries should not exceed four pages in length. It is easiest to read if you include figures and plots inline within the text and the sample paper template shows you how this is easily done. However, do not inundate the reader with material; you should find a way to summarize your results in at most two or three plots or tables. The figures and tables must be properly captioned. Material and ideas drawn from the work of others must be properly cited, and a list of references should be attached to the summary.

Papers will be graded using the following criteria:

- Theoretical and/or experimental motivation: 15%
- Description of experiment: 35%
- Analysis of data and results: 35%
- Style and English: 15%
- Papers not submitted by midnight after the oral exam will be deducted 10% for each day they are late.

MIT has excellent resources for technical writing and oral presentations (including on-line writing consultations) at http://writing.mit.edu/wcc. Use them!

4.6. Open ended project — 20%

The open ended project will occur in the place of either Experiment 2, 3, or 4 as proposed by the student group, lasting 5 lab sessions. The project should fall within Junior Lab's resources and scope of modern physics, but the design and goals of the project are to be determined by the student group.

Each group will submit a single project proposal as a formal 2-page written document. The proposal will be due on Day 5 of Experiment 1, and will count as 9% of the total grade. As this may not allow enough time to correct malformed projects before they could begin in Experiment 2, a rough form of the proposal — which nevertheless provides enough detail for the Junior Lab staff to judge its merits — will be due on Day 3 of Experiment 1. This rough proposal will count for 2% of the total grade, and will be graded as either a 2 (for an adequate proposal), 1 (for a proposal which shows little thought), or 0 (for no proposal). It is expected that all groups should receive full credit on the rough proposal. After all proposals are received, the Junior Lab staff will serve as a review committee which will: determine if any proposals are making competing requests for resources, and attempt to adjucate such conflicts; deterime if any proposals have components which are beyond the scope of the program, and scale back these components; and approve a coordinated schedule for the projects to go forward.

Projects will be evaluated based on a final formal write-up of comparable size and detail to those due for the other experiments, making up 9% of the total grade. Each student will submit an individually prepared report. There is no oral report for the project. Criteria for grading are themselves open ended, but will largely reflect how well the project goals were pursued — or adapted, in the case of unforseen circumstances.

5. SAFETY IN JUNIOR LAB

We are fortunate that there has never been a serious injury in Junior Lab. Prevention of injury is a matter of being aware of and having respect for pieces of equipment that are potentially dangerous. Nevertheless, since it is virtually impossible to set up a reasonably comprehensive and interesting set of experiments in modern physics without using equipment that has potential hazards, it is essential that students and staff be aware of the hazards, and exercise appropriate cautions.

5.1. Electrical Safety

The first rule is to never work alone. Some years ago a student was electrocuted in Building 4 by a laboratory power supply. Had he not been by himself, someone might have saved him.

All high voltage supplies are clearly marked as dangerous. Do not poke or probe into them. Turn off the supply if you need to change cable connections. The supply may be dangerous even when turned off if the capacitors have not discharged; always keep one hand in your pocket when testing any circuit in which there may be high voltages present so that if you get a shock, it will not be across your chest. Never go barefoot in the lab. Remember that it is current that kills. A good (e.g. sweaty) connection of 6 volts across your body can kill as well as a poor connection of 600 or 6000 volts.

5.2. Laser Safety

The 'Doppler-Free Saturated Absorption Spectroscopy' experiment utilizes a near-IR laser operating at 40 mW of output power. As such, it is classified as a Class 3b laser and all users must undergo MIT Laser Safety Training (EHS Course 371C, about 1.5 hours in length, offered by EHS every few weeks) prior to performing the experiment. All students should download the MIT Laser Safety manual and read, at a minimum, Section Two.XVI.D dealing with Class 3b laser controls.

A laser beam may not seem very bright, but if it enters your eye it will be focused by the lens of your eye to a pinpoint spot on the retina where the intensity is sufficient to destroy retinal cells. It is wise to terminate a laser beam with a diffuse absorber so that the beam doesn't shine around the room. Never examine the performance of an optical system with a laser by viewing the beam directly with your eye or reflector.

5.3. Cryogenic Safety

Liquid nitrogen, boiling at 77 K, is chemically inert, but it can cause severe frostbite. Wear gloves and protective glasses when transferring or transporting liquid nitrogen. Splashing against the skin should be avoided as much as possible, but it is generally not dangerous because the liquid will boil away rapidly, leaving only cold gas which will not transfer heat to the skin efficiently enough to cause injury. However, pooling of the liquid against the skin for even a short time will cause injury, and care must be taken to avoid this situation. Ultimately, the most ready source of injury when working with liquid nitrogen or other cryogens is not the liquid itself, but rather touching the cold metal surfaces of uninsulated valves and transfer vessels.

Liquid helium, boiling at 4.2 K, requires significantly more careful handling than liquid nitrogen, and should not be manipulated by Junior Lab students. When the cap on a liquid helium Dewar is left off, air flows in and freezes in the neck, forming a strong cement. When a probe is inserted, it may be frozen in solid. Pressure will then build up until something explodes. During the 8.14 'Superconductivity' experiment, never leave the Dewar cap off for more than a few seconds. Always ream out the Dewar before you use it. Check periodically to see that the probe is free. If the probe should freeze in the Dewar, get help immediately from any of the Junior Lab staff or instructors.

TABLE III: A table showing the radioactive sources used in Junior Lab and their approximate activities.

Experiment	Isotope	~ Activity (mCi)
Compton Scattering	^{137}Cs	0.4
Mössbauer Spectroscopy	^{57}Co	7
Rutherford Scattering	^{241}Am	0.2
Alpha Decay	Uranium Ore	5×10^{-6}
Relativistic Dynamics	^{90}Sr	8
	^{133}Ba	0.08
X-Ray Physics	^{241}Am	10
	^{55}Fe	0.7
	^{90}Sr	0.6
	^{57}Co	0.02
Calibration Sources	^{133}Ba	0.005
	^{109}Cd	0.008
	^{137}Cs	0.007
	^{57}Co	0.0001
	^{60}Co	0.0005
	^{54}Mn	0.0002
	^{22}Na	0.002

5.4. Radiation Safety

Radiation safety at MIT is under the authority of the Radiation Protection Office (N52-496). Junior Lab is accountable to that office for the safe handling and accountability of the sources used in the experiments. Junior Lab students are instructed in the safe use and handling of radioactive sources during the first class session of 8.13 by a member of the Radiation Protection Office. (See Table III.) Attendance at this session is mandated by Massachusetts state law. Meticulous care must be taken by all students and staff to insure that every source signed out from the locked repository in 4-361 is returned immediately after its use and signed in.

There are a few simple precautions to be taken for safely working with radioactive sources:

1. Don't handle radioactive sources any more than you have to.
2. Work quickly when transferring or positioning radioactive sources.
3. Never take a source away from the Junior Lab, even temporarily. The senior staff are legally responsible for the sources and must periodically account for their presence and condition.
4. Replace sources in the lead storage cabinet when they are not in use and ensure that the cabinet is locked at all times.
5. Keep sources away from your body.
6. Never bring a radioactive source near your eyes because they are particularly sensitive to radiation.
7. Be aware of the sources being used in neighboring experiments.
8. Remember ALARA – *As Low as Reasonably Achievable*!

Ionizing radiation damages tissue; any exposure should therefore be minimized. The unit of radiation exposure is the rem (roentgen equivalent man). Your inescapable dosage from cosmic rays and other background sources is 360 mrem yr^{-1}, which works out to 4.2×10^{-2} mrem hr^{-1}. The recommended limit to controllable exposure for a member of the general public is 100 mrem yr^{-1}, averaged over any consecutive five years. If you follow the Junior Lab guidelines, your exposure will be only a small fraction of the dose you receive from the natural background. A survey meter is available in 4-361 for you to check the radiation levels yourself.

Radioactive sources emit three types of radiation: high energy helium nuclei (alpha rays), electrons (beta rays), or photons (gamma rays). Most of the sources in Junior Lab emit only gamma radiation. Of the sources which do emit alpha or beta particles, most are enclosed in plastic or metals, which prevent particulate radiation from escaping. The exceptions are the ^{90}Sr source in the e/m experiment and the ^{241}Am source in the Rutherford Scattering experiment; both sources are in an enclosed apparatus. These sources should never be handled. Handling of open alpha- or beta-emitters can result in dangerous dosages to the skin.

The strength of a radioactive source is measured in curies (Ci). A one-curie source has an activity of 3.7×10^{10} disintegrations s^{-1}. The "absorbed dose" is a quantity that measures the total energy absorbed per unit mass; it is measured in rads, where 1 rad = 100 erg g^{-1}. The "equivalent dose" is measured in the units discussed above, the rem. The equivalent dose is derived from the absorbed dose by multiplying by a "radiation weighting factor" which is a measure of how damaging a particular type of radiation is to biological tissue. For photons (gamma rays) and electrons and positrons (beta particles), the radiation weighting factor is unity; for helium nuclei (alpha particles), it is 20; for protons with energy greater than 2 MeV it is 5; and for neutrons it ranges from 5 to 20, depending on the energy. When you use the survey meter in the lab, the readings are in rads, and you must consider the type of particle when you work out the equivalent dose.

For gamma rays with energy greater than 1 MeV, a useful approximation is that the equivalent dose due to a source with an activity of C microcuries is $5.2 \times 10^{-4} C E_\gamma R^{-2}$ mrem hr^{-1}, where R is the distance from the source in meters and E_γ is the energy of the gamma ray in MeV. For gamma rays with energy less than 1 MeV, this formula is still approximately true for a full-body dose. However, low-energy gamma rays deposit their energy in a smaller mass of tissue than high-energy gamma rays and can cause high local doses. For example, the local dose to the hands from handling a 10 keV source can be up to 25 times the value given by the above formula; hands, however, have a higher tolerance to radiation than inner organs or eyes.

The protective value of shielding varies drastically with the energy of the photons. The intensity of a "soft" X-ray beam of < 1 keV can be reduced by many orders of magnitude with a millimeter of aluminum while 1.2 MeV gamma rays from ^{60}Co are attenuated by only a factor of 2 by a lead sheet one-half of an inch thick. The best way to keep your dosage down is to put distance between you and the source. If you stay a meter away from most sources in Junior Lab, you will be receiving, even without any lead shielding, a dose which is much less than your allowable background dose. If, however, you sit reading the write-up with a box of sources a few inches away, you may momentarily be receiving ten to a hundred times the background level.