Gamma Spectroscopy, Attenuation and the Compton Effect.

Goals and Tasks (A and B are required, but with the advice and consent of the instructor, pick amongst the other task.)

A. Calibrate the gamma-ray spectroscopy system in terms of gamma energy.
B. Understand the gamma-ray spectroscopy system including the NaI detector, the photomultiplier tube (PMT), the amplifier, the multichannel analyzer (MCA), and the associated software.
C. Calibrate the gamma-ray spectroscopy system in terms of detector efficiency.
D. Study the effect of varying the distance between the source and the detector on the received signal. (Basically this is to look for an r^{-2} dependance.)
E. Study the effect on the received signal of introducing material of various thicknesses between the source and the detector. (Basically look for the exponential attenuation or absorption of the gammas by different material.)
F. Study the Compton effect in terms of the energy loss by the gamma's as a function of scattering angle
G. Study the Compton effect in terms of the probability of scattering at different angles (Klein-Nashima equation).

Readings:

A.C.Melissinos, *Experiments in Modern Physics*,
Radiation safety, p.143-147.
Nuclear line spectra, p 52-56
Related equipment, p. 194-208
Compton Scattering, p 252-265

W.R.Leo, *Techniques for Nuclea4 and Particle Physics Experiments, A How-to Approach, 2nd*, Springer-Verlag, Berlin, 1994 (QC793.46.L46)

Experiments in Nuclear Science AN34 Laboratory Manual 3rd, published by EG&G Ortec

Wall Chart of the Nuclei
Compton booklet
Manual for the MCA hardware and software

Additional handouts to receive:
Nuclear Instruments handouts
MCA, what to know handout
Radiation Safety and Units handout
Official Compton Scattering Protocol

Procedure:

During the semester leave the NIM BIN turned ON and leave high voltage turned ON. so that everything is in thermal equilibrium.

Before making a serious calibration, observe effect on line position, of changing high voltage (HV) by 1, 10, 25, 50 Volts up and down

Before making a serious calibration, observe the effect on line position of slightly changing gain of the amplifier.

Place a poker chip source on the plastic holder directly in front of NaI detector. (You should try an iron holder and see how does the signal changes.)

Toggle the MCA into the acquire-ON mode.
(F1 key)

Save each good run.(make your own private directory) and convert it to spreadsheet format

Energy Calibration procedure:

This is very similar to the method used for the Rowland grating experiment.

Determine your best method of locating the peak locations. Estimate the uncertainties.

Use the structure in the spectra to get more than one calibration pair from one spectral line.

Efficiency Calibration Procedure

Assume known activity of Cs-137 poker chip source. Calculate the number of gammas per second. Reduce to correct for estimated geometric effects. Compare actual measured counts per second with calculation.

Attenuation with Distance Procedure

1. Vary the distance from the source to the detector.
2. What distance do you use because the detector is 3-D?
3. Which measure of the intensity should one use:
   Counts in peak channel;
   Counts in full peak;
   Counts in full peak minus background; or Counts in entire spectra minus a no source run.

Attenuation with Shielding Procedure

1. Test if gammas scattered back into detector
2. Measure the effect on count rate on aperture size
3. Fix detector and source distance but vary placement of shielding
4. Vary size of shielding

Compton Scattering Procedure

The basic procedure is that gamma radiation from a CS-137 source is directed at an aluminum target. A NaI detector can be rotated about this target, and spectra is collected at various scattering angles. The shift in the energy of the peak and changes in intensity are measured from the zero angle measurements.

In this part of the experiment, a higher activity source is used, which your instructor will set in the pig. Before this source is brought out, you should check the operation and calibration of the system with a Cs-137 check (pokerchip) source, and align lead bricks to collimate the radiation.

Background subtraction will be important. This is done by recording a second spectra at each angle but with the target removed. The data collection time for the two spectra at a given angle should be the same.

Which measure of the intensity should one::

Counts in peak channel;
Counts in full peak;
Counts in full peak minus background; or Counts in entire spectra minus a no source run.

Going Further

Gamma spectroscopy of common items: lantern mantels, fiesta ware, wipe of computer screen

Questions:

Calibration:

1. Even from a radioactive source that produces gamma rays of a single energy, the observed spectra has a number of features. How can these features be used to provide additional calibration information?
2. In what situations is it better to use the number of counts in the peak channel, the number of counts in the entire peak, and the total number of counts received (after correcting for background)?
3. If you know the current activity of a radioactive source how can you calibrate the detection efficiency of the detector?

Gamma-ray spectroscopy system:

4. How does a PMT work?
5. How does the NaI detector work?
6. Compare the signal from the PMT before and after the amplifier in terms of size and shape.
7. While the computer is being used as an MCA there is a plot of the screen. On this plot, what are the horizontal and vertical axes? Or what is an MCA?
8. Explain the source of the various features in the gamma spectra as observed by this detection system?
9. How does this NaI detector-PMT create a signal proportional to the energy of the incident gamma?
10. What does “dead time,” “live time” and “real time” mean? And why are these concepts important?

Nuclear physics

11. For each of the gamma source, what reaction(s) produce the observed gamma rays.

Attenuation:

12. Can gamma rays that are scattered in the attenuating material reach the detector? If so by what mechanism? How can these scattered gammas be discriminated against?

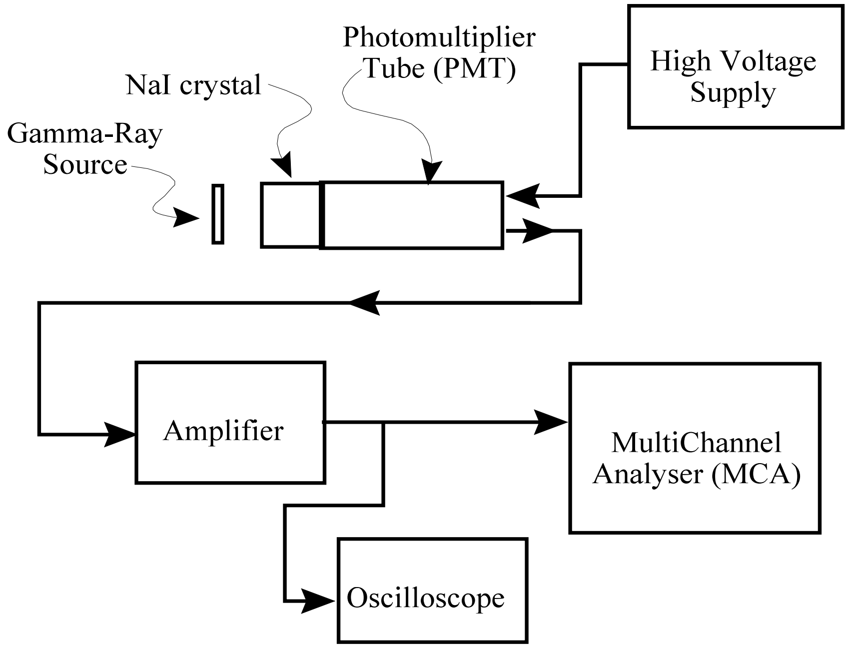

Figure 1 Block diagram of the gamma spectroscopy system

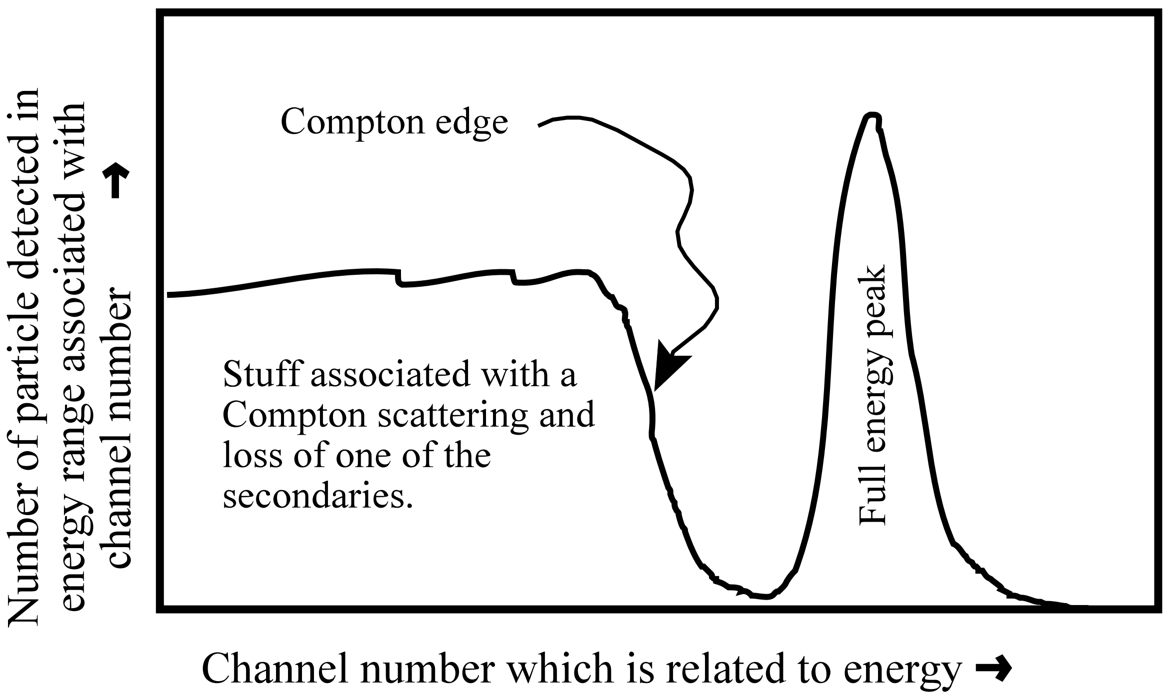

Figure 2 A typical gamma spectrum taken with a detector using NaI (Sodium Iodine) crystal. All of the structure in the spectrum is associated with gamma ray that when initially emitted all had the nearly same energy.

What to Learn about the MCA Program Used in Gamma Spectra

I. Getting Started

A. To start the program at: **c:\>** type **mca**

B. Use the key associated with highlighted letter to select a menu item.

C. Use the ESCAPE key to move up a menu tree.

D. On the plot, the horizontal scale is channels. Each channel is associated with a small range of heights of the incoming pulse and for an NaI detector this pulse height is proportional to the energy deposited in the NaI crystal by the incident gamma. The vertical scale is number of event in a given channel.

E. Move markers with left and right arrow keys, Faster movement with CTRL and arrows, and read marker position in upper right. Counts at marker position see Status Page 3
(Change status page using ***page up/down***)

F. Use the function key overlay chart to learn what shortcuts are available from the function keys.
F1 to toggle Start and Stop of acquiring data
Shift F2 to erase current data
F4 to cycle through vertical scaling method.

G. To quit program from menu select **EXIT**.

H. The input range is 0 to +8 volts.

I. To change the directory into which data is saved use:
Util Command cd *"directory path"*
Please make your own directory under c:\mca\students using **md** *" me"*

II. Important parts of the manual to read.

A. Chapter 3 Introduction ALL OF IT

B. Chapter 4 Getting Acquainted
- 4-4 Display spectrum from file
- 4-5 Status pages
- 4-16 Controlling the Display
- 4-17 Changing the vertical scale

C. Chapter 7 is a break down of the functions available from the menu tree.
- 7-1 Acquire On-OFF
- 7-2,3 Presets Live, Real Total, Markers
- 7-10 Calibrate\Manual\Energy
- 7-15 to26 Display
  - 7-17 overlap
  - 7-17 vscale
  - 7-20 expand
  - 7-24 cursor, Markers
  - 7-25 ROI
- 7-27 Move\Data **VERY IMPORTANT for saving data**
- 7-54 to 58 Util\ Dir, Print,
- 7-58 MENU **VERY IMPORTANT** because this is the access key to the data manipulation and analysis programs described in Chapters 10 to 19

D. Chapters 10 to 19 Basic Spectroscopy Programs

10-1 to 5 Introduction

19-1 to 13 LOTCNV (convert data files from binary to text form)
VERY IMPORTANT for converting saved data files into spreadsheet readable form.

III Need to be able to:

A. Manual calibration of energy scale. From menu **Calibrate \ Manual \ Energy** See Manual page 7-10.

B. Set Preset to stop data collection for a set Real Time, Live Time or Number of Counts. From menu **Acquire \ Preset** Set possible presets that are not used ones to zero. See Manual pages 7-2,3.

D.. Save and retrieve data. From Menu: **Move \ Data \.** Use From **RRH** which is the display *To* **filename.dat** use defaults for header and eff files. See Manual page 7-27.

E. Convert saved (binary) datafiles to something a spreadsheet can read From Menu **UTIL \ Menu** then **Reports** from groups (left column, use page up/down to select) then **Convert Data to Lotus Format** (center column, use arrows). Use **F2** to execute the program, then give name of binary and name of new file to create. To return to MCA screen use **F10**. See Manual pages 19-1 to 13.

G. To get DOS Prompt from menu **Util \ System** Then can issue DOS commands like: dir to see list of files

cd	to change directories
del filename.ext	to delete file
copy old_name.ext new_name.ext	to copy files

Note data acquisition continues while you are at the DOS prompt.

Type **EXIT** to return to MCA program.

H. To adjust the Lower Level Discriminator from the menu use **Setup \ ADC \ Coarse LLD** or **Fine LLD** . Also of use **Setup \ ADC \ Zero** and **Setup \ ADC \ ULD**

Discriminator, Single Analyzers and Multichannel Analyzers

In nuclear and high energy physics most experiments depend on its associated the electronics. Usually, an electrical pulse is created by a detector when a particle is detected. These pulses may contain information about the detection event such as when it occurred, where on the detector the event occurred, or the energy of the detected particle. Small signals are made larger with an amplifier, The shape, and duration of a signal pulse may also be changed by special amplifiers (by integration or differentiation of the signal). In most cases, there is some level of electrical noise on the signal wires and the real signals must be sort out from the noise. Frequently a discriminator, or a single channel analyzer (SCA) is used for separating the signal from the noise.

If after an amplifier, pulses associated with real events are about 2 volts in peak amplitude, and the noise is 0.07 volts in amplitude, then separating the signal from the noise seems simple enough-- just pay no attention to pulses less than a volt high. This is basically what a discriminator or single channel analyzer does. One defines what a valid input is and every time the input pulse meets this selection criteria, an output pulse is produced. This output pulse carries only the information: "A valid event just happened." This output pulse is often a + 5 Volt pulse similar to a digital logic TTL pulse. In addition to the existence of a valid pulse, there is the information as to when the pulse occurred.. There are several ways of synchronizing the output to the input so that the relative timing remains the same.

When using a **discriminator**, one defines the minimum voltage level for a valid pulse. That is you set the discriminator level to 1.4 volts, and any pulse with a peak height of 1.4 volts or greater results in an output pulse. Many discriminators delay the output signal slightly so that is set out a set delay after the pulse reaches a set fraction of its peak height (NOT the discriminator level). These are called constant fraction discriminators (CFD's).

A **single channel analyzer** is like a discriminator with added features. One can set the SCA to the Integrate mode (INT) where it will operate like a discriminator. When using the Window mode one has the added feature of defining both a maximum acceptable peak height as well as the minimum. This would be useful if the detector was detecting two types of events with different pulse peak heights and you were interested in counting the number of events associated with the smaller pulses. You would then put the SCA window around the signal of interest. That is you would set the lower level (LL)of window above the noise but below the height of the signal of interest. Next you would set the upper level (UL) of the window between the two pulse heights (often using a knob labeled Window or UL).

Often on an SCA, one actually specifies a lower level and the height of the upper level above the lower level. This is useful in analyzing a complex spectrum of signal pulse heights. For example, if you break the spectrum form 1 to 10 volts into a number of "channel" each 0.2 volts wide by set the height of the window at 0.5 volts, and then counting for a minute for each of the following lower level settings: 1.0, 1.5, 2.0, 2.5, . . . 9.5 volts. Plotting the number of counts recorded as a function of the lower level setting will yield a histogram of the incoming signals pulse height.

If you need to do a lot of this, the counting gets rather tedious, especially if the window height is something like only 0.05 Volts. Fortunately, someone invented the **multichannel analyzer** (MCA). This device looks at all of the "channels" at once. That is it break its input range into a number of pulse peak height ranges (channels) and counts the number of pulses falling into each range. Usually an MCA will display the resulting histogram and allow some numerical manipulation of this data. Note that often the pulse peak height is associated with the energy of a single quanta of some incident radiation and thus the histogram is an energy spectra of the incident radiation.

Nuclear Safety and Units

General Goals:

To provide a sufficient information about radiation safety to allow students to safely work in PAS 284.

Reading:

See A.C.Melissinos, *Experiments in Modern Physics*, p.143-149.

Introduction to Radiation Safety, by the University of Arizona Radiation Control Office (attached to this document)

Units used when discussing radiation

When discussing radiation safety, it is necessary to know how radiation is measured. That is basically a discussion of units.

The *curie* (abbreviated Ci) is a measure of the activity of the sample that is the number of nuclear disintegrations in a given time. Specifically the curie is 3.7 X 10^{10} disintegrations per second, which is the activity of a gram of radium. In the SI system of units, the curie has been replaced by the *becquerel* (Bq) with 1 curie = 37 X 10^{9} Bq, so a Bq is one disintegration per second.

The activity of a source (in Ci or Bq) is one way to describe the amount of radiation present. An alternative method is to give the *flux* of radiation. That is the number of quanta (alpha, beta, gamma, protons, chickens . . . or whatever) incident on a unit area per unit of time (for example the number of betas incident on 1 cm^2 /s).

There is another type of radiation unit that is related to the interaction of radiation with living tissue. As radiation passes through matter, it interacts and in general deposits energy in the matter. A *rad* of radiation will deposit 100 ergs of energy for each gram of tissue it passes through. Starting from the activity of a source or the flux of the radiation and converting to rads is not a simple process. This involves details of the interaction between the specific type of tissue and the specific type and energy of the radiation. Recently SI replaced the rad with the *gray* (Gy). A *gray* of radiation will deposit 10,000 ergs of energy for each gram (or 1 J/kg) of tissue it passes through (100 rad = 1 Gy).

Even when losing the same amount of energy in a given bit of living tissue, different kinds of radiation cause different degrees of damage. This is because for some type of radiation a given particle may interact relatively infrequently, but deposits a relatively large amount of energy during each interaction, while a particle of different type of radiation, may interact frequently, but lose only a small amount of energy in each interaction. The energy deposited per gram of tissue may be the same but the damage is different. Thus a further set of units is needed.

The *rem* (roentgen equivalent unit (a roentgen is basically 1 rad of gamma's)) is the standard old unit for radiation damage and the sievert (Sv) is the new SI unit. 100 rem = 1 Sv. The amount of radiation present in Gy, is multiplied by an RBE (relative biological effectiveness) factor to yield the amount of radiation damage in sieverts. The RBE for x rays, gammas and betas is 1, protons it is 10 and for alpha it is 20. Thus the same number of rads or grays of alphas in much more damaging the equivalent amount of gammas.

Note the rem or the sievert do not indicate how quickly the damage was done. So often the radiation field is reported in rem/hr or mrem/ year or Sv/year. Acceptable limits of radiation exposure have decreased over the years as more information on the long term effects of radiation have become available.

Typical Exposures

Typical exposures **per year** to a member of the public may include:

- 35-60 mrem (~0.0005 mrem/hr) from cosmic rays (strong altitude dependance)
- 35-70 mrem (~0.0005 mrem/hr) from natural radioactive sources
- 30-350 mrem (~0.0005 - 0.005 mrem/hr) from all natural radioactivity that includes sources within the body
  - (25 mrem from K^{40},
  - 1 mrem from C^{14},
  - remainder from Ra^{226})
- 100 mrem from medical x-rays.
- 4 to 8 mrem (0.0005 to 0.001 mrem / hr) estimate of exposure in the Physics and Atomospheric Science Building at the University of Arizona.
-
- 0.001 **mrem/hr** typical poker chip source at one meter.

Legal Limits of Exposure

These limits are set by various government agencies and are subject to change.
For the general public **(Or Students)** the acceptable whole body exposure is:
100 mrem/yr = 1 mSv/yr,
For radiation workers the limit is
5000 mrem / yr.
If the radiation exposure is limited to the skin or extremities, the limit is even higher.

One of our typical "poker chip" sources will produce a radiation field a one meter of about 0.001 mrem/hr. A student working with one of the "poker chip" sealed source would reach their annual full body radiation exposure in about 100 hours. This assumes a distance of one meter and no shielding. Note that there are about 75 hours of advanced lab per semester. Double the distance to two meters and the time increases to 400 hour.

Official Information:

Arizona Regulations dealing with radiation safety and radiation workers' rights can be found on the table near the radioactive source cabinet.

On the door of the radioactive source cabinet are:

Notice to Employees
Radiation Emergency Procedure
Basic Laboratory Procedure for Radioactive Materials
Rules for Package Radioactive Waste
Radioactive Materials Approval List (Basically an inventory of sources requiring approval)

Sources and Location:

The radioactive source cabinet is in the North East (After entering the room this is the far left) corner of PAS 284. This cabinet should be locked unless PAS 284 is occupied.
In PAS 284 there are three sources that require approval.

- 15 mCurie Cs-137 is a beta and gamma source used for Compton scattering experiments. This sealed source stored in a lead pig inside the radioactive source cabinet. This source is quite hot, and **SHOULD BE HANDLED ONLY BE THE LAB MANAGER** or other train individuals and then only at arms length and for as short of time as possible. The lead pig used for storage and the lead shielding used in the Compton experiment reduce the emitted gamma radiation to a level similar to a "poker chip" source.
- 0.001µCurie Am-241 is an alpha source used for studying the range and energy loss of alphas in gases. This source is a foil implanted with Americium and is mounted in a 9 by 5 inch vacuum chamber. It is stored in the radioactive source cabinet. Am-241 is an alpha emitter and all alpha emitters are potentially dangerous because alphas can cause serious cell damage. This damage usually only occurs if the alpha emitter is ingested because alphas have a very limited range. Virtually all alphas emitted by this source all absorbed by the vacuum chamber housing. Unless the housing is opened this source is quite safe. **NO NOT OPEN THE VACUUM HOUSING**
- 16 gram of Pu-239 mixed with beryllium is a neutron source used in neutron activation experiments. This source is in a large brown drum (a neutron howitzer) stored near the radioactive source cabinet. This drum is filled with paraffin that is an excellent shielding material for neutrons

The cabinet also contains a number of low activity test sources the size of a poker chip, lantern mantles containing thorium and other low level radioactive materials.

Waste

In these experiments no waste should be generated and neutron activated material are stored in the neutron howitzer after the experiment. ,

Accidents /emergencies

If you believe, a source (including an exempt "poker source") is damaged contact the lab manager or your TA immediately.

If the radioactive sources are out of the cabinet and there is a fire in the building, please inform the police, or fire departments or the building monitor.

Working procedures:

An official protocol is describing the use of each of the radioactive sources requiring approval. This is a legal document outlining the operational procedures. If you are preforming an experiment using one of these sources, you should get a copy of the associated protocol and follow the protocol.

The basic rule of thumb when working with radioactive material is to take all reasonable steps to reduce exposure. The rule is often referred to as ALARA, As Low As Reasonably Achievable. The three basic methods of reducing exposure are:

- minimizing exposure time,
- maximizing distance (Intensity $\propto 1/r^2$), and
- using shielding
  - Lead for most forms of radiation
  - Paraffin for neutrons

Applying this rule requires that one stop and think before using a radioactive source. Think through what you are about to do.

Lab Rules:

11. No eating or drink in PAS 284! No open food or beverage in PAS 284. Any open food or beverage brought into PAS 284 must be destroyed.
12. The lab PAS 284 must either be occupied or locked at all times.
13. Do not remove any radioactive source including an exempt "poker source" from PAS 284
14. Only Lab manager or specially trained TA or Instructor may move the 15 mCurie Cs -137 source, open the neutron howitzers, or open the Range of Alpha chamber. Please move at least 2 meters from the area when these processes are occurring.
15. Store radioactive sources in the cabinet when not in use.
16. At the end of lab check the inventory to verify all sources are stored.
17. Do not eat a source
18. Do not put a source in your pocket
19. Do not hold a source any longer than necessary

Additional Concerns:

If you are concerned about some aspect of the radiation safety in PAS 284 please discuss it with the Lab Manager or Someone at the Radiation Control Office 626-6850 or rcohelp@u.arizona.edu or http://www.radcon.arizona.edu/.

Pregnancy:

Anyone who is pregnant, thinks they may be pregnant, is engaged in activities to become pregnant should take special steps to limit exposure, and should (but are not required to) discuss the situation with the Lab Manager or someone at the Radiation Control Office 626-6850 or rcohelp@u.arizona.edu or http://www.radcon.arizona.edu/.

Additional Training:

Additional radiation safety training is available through the Radiation Control Office 626-6850 or rcohelp@u.arizona.edu or http://www.radcon.arizona.edu/.