The illustration above shows the exterior of the W.A.S. STARGATE observatory, located on Camp Rotary property off North Ave. on 29 mile road. The building contains a 12½" cassegrain telescope of 200" focal length. The use of this observatory is the privilege of all members & guests of members. The equipment within the building will allow observational astronomy to be conducted at all times, weather permitting.
The W.A.S.P. is the official publication of the Warren Astronomical Society and is available free to all club members. Requests by other clubs to receive the W.A.S.P. and all other correspondence should be addressed to the editor. Articles should be submitted at least one week prior to the general meeting.

W.A.S.

Warren Astronomical Society
P.O. Box 474
East Detroit, MI 48021

President: Frank McCullough 254-1786
1st V.P.: Roger Tanner 981-0134
2nd V.P.: Ken Strom 977-9489
Secretary: Ken Kelly 839-7250
Treasurer: Bob Lennox 689-6139
Librarian: John Wetzel 882-8816

The Warren Astronomical Society is a local, non-profit organization of amateur astronomers. The Society holds meetings on the first and third Thursdays of each month. The meeting locations are as follows:

1st Thursday – Cranbrook Institute of Science
500 Lone Pine Road
Bloomfield Hills, MI

3rd Thursday – Macomb County Community College – South Campus
K Building (Student Activities), 14500 Twelve Mile Rd., Warren, MI

Membership is open to those interested in astronomy and its related fields. Dues are as follows and include a year’s subscription to *Sky and Telescope*.

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<tr>
<th>Membership</th>
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<tr>
<td>Student</td>
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Stargate Observatory Chairman: Ken Strom 977-9489

Stargate Observatory is owned and operated by the Warren Astronomical Society in conjunction with Rotary International. Located on the grounds of Camp Rotary, Stargate features a 12½” club-built Cassegrainian telescope under an aluminum dome. The observatory is open to all club members in accordance with the “Stargate Observatory Code of Conduct”. Lectures are given at Stargate Observatory each weekend. The lecture will be either Friday or Saturday night, depending on the weather and the lecturer’s personal schedule. If you cannot lecture on your scheduled weekend, please call the Chairman as early as possible or contact an alternative lecturer. Those wishing to use Stargate must call by 7:00 p.m. on the evening of the observing session. The lecturers for the coming month are:

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<tr>
<th>Date</th>
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<tr>
<td>Mar 4/5</td>
<td>Doug Bock</td>
<td>533-0898</td>
</tr>
<tr>
<td>Mar 11/12</td>
<td>Ken Strom</td>
<td>977-9489</td>
</tr>
<tr>
<td>Mar 18/19</td>
<td>John Root</td>
<td>464-7908</td>
</tr>
<tr>
<td>Mar 25/26</td>
<td>Lou Faix</td>
<td>781-3338</td>
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<tr>
<td>Apr 4/5</td>
<td>Stephen Franks</td>
<td>255-7215</td>
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<tr>
<td>Apr 11/12</td>
<td>Frank McCullough</td>
<td>254-1786</td>
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<tr>
<td>Apr 18/19</td>
<td>Ron Vogt</td>
<td>545-7309</td>
</tr>
<tr>
<td>Apr 25/26</td>
<td>Alan Rothenberg</td>
<td>355-8844</td>
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<tr>
<td>Apr 29/30</td>
<td>Doug Bock</td>
<td>533-0898</td>
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</table>
Warren Astronomical Society's Coming Events

March 3 - Meeting at Cranbrook Institute of Science commences at 7:30pm. Program will be "Using Setting Circles" given by Roger Taner.

March 10 - Workshop subgroup meeting at Doug Back's.

March 11 - Astrofest in Ann Arbor at 7:30pm in Modern Language Building. Program will be "Asteroids - Promise & Threat."

March 12 - Open business meeting at 5:00pm with Deep Sky meeting at 7:30 at Alan Rothenberg's. If clear observing session will be held at Doug Back's new property. For more information call Doug at 533-0898.

March 17 - General Meeting at Macomb Community College, K-building. Beverly Persha's slide show "Astronomical Reflections Around the World" will be shown. Be sure to attend tonight as the 1983 Group Photo will be taken!!!
LETTER FROM THE PRESIDENT

First of all I would like to thank everyone for the confidence you have shown in me during election time. I am looking forward to this year as your President and am very excited about constructing and completing the upcoming projects and activities for the following reasons.

My excitement is generated by the officers, committee personnel, editor and the people supporting our paper. Basically all new personnel I have been, in the W.A.S. since 1968 and in that time I have met and worked with many enthusiastic people, but I don’t think I have ever seen so much enthusiasm and willingness to work and accomplish so much not only for themselves (officers), but especially for the members in our organization.

The programming is good and getting better. The observatory is under maintenance and by the first warm day of spring should be ready to use!!! Not analyze what’s wrong with it at that time. The treasury was left in a superior condition by our past treasurer, John Wetzel, who is now our club librarian. Our new treasurer, Bob Lennox, whom is extremely competent, is working with a system which you must first completely understand before it can work effectively for not only himself but also for the membership. Our secretary is the only one besides me to return from last year’s officers and has been working diligently supplying me with names and addresses of whom we now correspond with and exchange our club publication. It is our concern that a major effort be made to make sure everyone on the mailing list will receive a full year’s supply of The WASP.

At this time I do want to apologize for any delays or issues not received in the past, this will be rectified. I also want to thank people like the Hills, Ken Wilson, and many others who have sent articles for our publication. It is not only nice to have the articles, but is nice to still be in touch with old members and friends.

I know you will be enjoying the WASP this year for three major reasons. 1) The appointment of our new editor Judy Butcher, who is an audio/visual technician and works in graphic arts at the University of Detroit. She has taken the WASP and made it more than words on paper, but also a visually stimulating and attractive publication. With the following issues, I need not say anymore! 2) The articles we receive out of state as I mentioned earlier. 3) The fascinating articles we have received from club members such as: Bruce Johnston, Stephen Franks, Ken Kelly, Judy Butcher, John Wetzel, Ken Strom, Roger Taner, Jon Boditoi, Larry Kalinowski, John Pazmino, Doug Bock and many others. We always encourage more articles, technical or just an evening observing in your back yard.

Our P.R. program is under full swing and our new field trip committee consisting primarily of Alan Rothenberg is running smoothly. He has taken us to the Detroit Science Center and the Jackson Space Museum. Many more field trips are planned for the future. Thanks Alan!

Our purpose as a club is to promote Astronomy at a beginning and advanced amateur level. We consider ourselves a friendly organization and hope no one will feel inhibited asking questions about astronomy no matter how silly or primitive they may seem. We have people more than happy to help you and if they can’t they will be glad to direct you to someone who can.
We welcome all visitors and other club members to join us at our meetings and activities. We also more than welcome correspondence from other clubs such as club newsletters. We will exchange or if you are interested in subscribing to our publication, a small subscription fee is asked.

In closing I think this is the finest organization in Michigan, if not in the country. We’ve got great members with a lot of talent in different areas and we hope to reap what talents and ideas the membership has to offer.

No matter how much we learn we never stop learning. Amateur Astronomy does not come to a dead end, because if we allow ourselves, we can meet new people, with new ideas. We still learn.

Looking forward to a wonderful year working with and meeting new people!!

Respectfully yours,

Frank R. McCullough

President, Warren Astronomical Society
### Sky Calendar February 1983

#### An aid to enjoying the changing sky

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<tr>
<th>SUNDAY</th>
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**Diagrams are for mid-twilight (about 1/4 hour after sunset or 1/4 hour before sunrise), except Feb 13, as noted.**

**Activity:** Observe Venus and Mars each evening, about 1/4 hour after sunset. Watch Venus get higher each night, Mars lower. When will they pass?

- **Morning:**
  - Feb 1: Venus, Mars, and Aldebaran form a triangle near the eastern horizon.
  - Feb 2: Venus and Mars are closer together.

- **Evening:**
  - Feb 1: Venus in the west after sunset, Mars in the east after sunset.
  - Feb 2: Venus and Mars are closer together.

**Mercury:**
- Feb 1: At greatest elongation, 20° W of Sun.
- Feb 2: At its farthest from the Sun.

**Saturn and Spica:**
- Feb 1: Saturn in SSW, Spica in SW.
- Feb 2: Saturn moves closer to Spica.

**Moon:**
- Feb 1: Full Moon, 17th.
- Feb 2: New Moon, 2nd.

**Planets and Constellations:**
- Feb 1: Zodiacal light seen in the eastern sky.
- Feb 2: View the Milky Way in the evening sky.

**Watching for Venus and Mars:**
- Feb 1: Venus and Mars are visible in the eastern sky.
- Feb 2: Venus and Mars are closer together.

**Celestial Events:**
- Feb 1: Mercury at greatest elongation, 20° W of Sun.
- Feb 2: Venus at its farthest from the Sun.

**Preparation Tips:**
- Feb 1: Use binoculars to observe the Pleiades and Aldebaran.
- Feb 2: Use a telescope to observe the moon's phases.

---

Robert Victor and Jenny Pon

**Extra Subscription:** 5.00 per year, from Sky Calendar, Abrams Planetarium, Michigan State University, East Lansing, Michigan 48824-1324.

**ISSN 0723-6314**

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**Use this page to measure angular distances between objects on diagrams below.**
February Evening Skies

This chart is drawn for latitude 40° North, but should be useful to stargazers throughout the continental United States. It represents the sky at the following local times:
- Late January 10 p.m.
- Early February 9 p.m.
- Late February 8 p.m.
- Early March 7 p.m.

This map is applicable one hour either side of the above times.

The planets are not plotted on this map. Check the Sky Calendar for planet visibilities. At chart time 9 objects of first magnitude or brighter are visible. In order of brightness they are: Sirius, Capella, Rigel, Procyon, Betelgeuse, Aldebaran, Pollux, Deneb, and Regulus.

In addition to stars, other objects that should be visible to the unaided eye are labeled on the map. The double star (DB 1) at the bend of the handle of the Big Dipper is easily detected. The famous Orion Nebula, a cloud of gas and dust out of which stars are forming, is marked (Nb) in that constellation. The open or galactic cluster (OGC) known as the "Mebkh" can be located between the Gemini twins and Leo. The position of an external star system, called the Andromeda Galaxy after the constellation in which it appears, is also indicated (CLX). Try to observe these objects with unaided eye and binoculars.

-D. David Batch

Extra Subscription: $5.00 per year, from Sky Calendar, Abrams Planetarium, Michigan State University, East Lansing, Michigan 48824-1324. ISSN 0723-6514
HOW TO MAKE A POSITION MICROMETRE
by Stephen Franks

Though I have been interested in astronomy for about twenty years, it’s only the last few that my main attention has been drawn to binary stars. To the casual observer, binaries may present few sources for amusement. The more interesting pairs have many color variations. Some are subtle while others, like Albireo and Gamma Andromedae, quite striking. Binaries can be used to severely test the telescope’s optics as well our acuity. Alpha and Eta Piscium are good examples.

Sightseeing and testing is all well and good but over the long haul won’t hold a person’s interest forever. The most entertaining nights at the telescope for me have been those where I took prolific notes and measures of things I have seen. I guess it’s part of human nature that a person’s enjoyment is apparently proportional to the amount of work one creates for himself. This last summer, I decided to make some kind of which would allow me to make personal measurements of the components of binaries as to separation and position angle-namely, a Position Micrometre.

Bi-filar micrometres can again be purchased commercially but not without a high investment. Making your own equipment has two distinct advantages: it’s cheap and fun! After a few bad starts, I began making successful measures. Now I could not only look, but, with great satisfaction, record what I saw. These, coupled with old readings (Rev. Webb’s catalogue published in 1917 for instance), have allowed me to witness their motions and have given me my niche in this most diverse hobby. As a bonus I found it possible to observe and measure the distance and progress of motion of Jupiter’s moons, close planetary conjunctions with stars, the passage of Comet Austin against the starry background to name a few. With a little time puttering around the old workshop you can allow your telescope to give you hard data.

Work is done solely at the telescope’s eyepiece, and the first thing to do is to select one that gives a moderate magnification. A 25-millimetre is about the best for general use in the work we are about to do. If the eyepiece is of the so-called negative type, the cross hairs we are to use will be placed between the two lenses; if the eyepiece is positive, the hairs will be placed in front of the field lens. The cross hairs, of course, are placed in the focal plane in both cases.

It is only fair to warn the reader at this point that since there is no simple method of illuminating the hairs or wires when the instrument is in use. It is only practicable in the vicinity of a bright star or planet, or on a moonlit night. I will leave the problem of illumination up to your inventiveness.

The cross hairs which form the essential part of the Micrometre may be built into the telescope as follows: A small flat metal ring is made to fit snugly into the eyepiece tube (in the case of the negative eye-piece) or into the adapter tube of the telescope (in the case of the positive eyepiece).
The inside diameter of the ring should be equal to the diameter of the diaphragm-hole in the negative eyepiece; or as large as the focal image of the object-glass when using a positive eyepiece. This ring can very easily be made from a piece of tin, or plastic (see Figure 61 A).

It is not important to make the spaces between the parallel hairs of any particular width. In fact, it is better to vary them because this will greatly simplify matters when you use the instrument to judge the separation of two objects. The lone vertical hair and the central horizontal hair should be perpendicular to each other, and they can be made so by use of the circle scratched on the flat ring (see again Fig. 61 A).

Divide the circle into four equal sections. Place a straightedge across each opposite pair of points and use a needle to make a scratch running through these points and the diameter of the circle. Lines drawn through each set of scratches will prove perpendicular to each other, and they will be of great aid in fastening the hairs to the ring.
Fig. 61  Position Micrometre

A: Metal or celluloid ring
   Cross hair circle
   Scratch
   Prime horizontal
   Vertical

B: Cross hairs
   Adapter tube
   Pointer
   Dail
   Collar

A. Top view.  B. Side view, (of complete device)
And now we come to a consideration of what we shall use for the hairs. In the first place, they should be as fine as possible; and they should also be strong and of uniform thickness. The finest obtainable magnet wire (which can be purchased in electrical shops) answers our needs.

After the foundation scratches have been made on the ring, as described previously, it is time to fasten the wires to it. To make certain that the wires will be set in the ring at the proper tension, place the ring on a small raised platform and hang weights from each end of the wire.

Now that the wire has been stretched tightly across the two corresponding scratches on the ring, it may be fastened by a drop of epoxy or liquid solder. When the epoxy or solder has dried, the weights may be removed and the extra length of wire clipped away. The process is the repeated for all the other parallel and cross wires.

When all the hairs have been fastened they should be protected by a cardboard ring. The outside diameter of this protecting ring should be slightly smaller than the first ring, and its inside diameter, slightly larger.

The ring, with its cross hairs firmly in place, is now fitted in to the eyepiece in a position determined by whether the eyepiece is positive or negative, as has already been explained. And when the eyepiece has finally been fitted with a fixed micrometre, a dial is needed so that visual observations may be translated into standard units of distance.

Next installment will cover the dial which is used for determining the position angle.
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Extra Subscription: 45.00 per year, from Sky Calendar, Abrams Planetarium, Michigan State University, East Lansing, Michigan 48824-1324.

ISSN 0733-8314
THE CRAB NEBULA

The Crab nebula is one of the most complex and interesting objects in the sky. It is located about 1 degree NW of Zeta Tauri, the southern tip of the of the bull's horn in the constellation Taurus, see the map below (from Norton's).

The Crab nebula is an expanding gas cloud resulting from a supernova explosion about 900 years ago. There is a recorded account of a 'guest star' appearing near Zeta Tauri given in two Chinese astronomic records in 1054 AD. It is generally agreed that these refer to the Crab supernova. It is interesting that no mention of a 'new star' is found in the European astronomical records of the period. This is rather amazing because the supernova was estimated to have a magnitude of -11, which is bright enough to be seen in the daytime. This is 1.5 million times brighter than the brightest star, Sirius, 100,000 times brighter than Venus at its brightest, and 1/10,000 the brightness of our own sun.

The nebula is mostly hydrogen and helium gas which is a trillion times thinner than our atmosphere. The nebula is composed of two parts, the filaments, which emit mostly red light and are enveloped in the second part, a very thin, amorphous cloud which emits more blue light, see below.
A spectrum analysis of the light from the nebula reveals some unusual properties which are not common for typical planetary nebulae. The light from the filaments shows the typical spectrum of an emission nebula, a few bright lines of neutral and ionized helium/hydrogen, and a few other atoms. The amorphous nebulosity, however, shows a continuous spectrum of light which is strongly polarized, very unlike an emission or reflection nebula.

This leads us to look at the power source of the nebula to explain these unusual characteristics. The star which powers the Crab nebula is the southern most of a pair of faint stars in the apparent center of the nebula. Optically this star is only 14th magnitude and 1000 times fainter than the whole nebula. The solution to the puzzle is found by combining observations made at radio and X-ray wavelengths and some theory as to the result of a supernova explosion.

As the field of radio astronomy opened up the Crab nebula emerged as one of the four brightest ‘stars’ in the radio sky. The first X-ray observations showed that the Crab was also a very strong X-ray source, emitting about 100 times as much energy in X-rays as visible light. About this time several theoretical studies of supernovas proposed that since the nuclear explosion occurs in an intermediate layer in the star, the center of the star could be compressed into an incredibly dense object called a neutron star. These objects were first discovered by the radio pulses they emitted during rotation, which was at such a high frequency that a neutron star is the only object small enough to account for it. They were given the name Pulsars. For most of the pulsars discovered, there were no optically visible objects, however, the first one which was found to have a visible star associated with it was the 16th mag. star in the center of the Crab nebula. The pulsation frequency of the Crab pulsar is an extremely rapid 30 Hz. After this was discovered, the Crab pulsar was studied intensively and found to be optically pulsing at the same 30 Hz, see the pictures below.
The Crab pulsar appears to be a very tiny, very rapidly rotating neutron star, with a very strong magnetic field, which emits radio waves and visible light at the poles. The pulses are generated when the beam sweeps across the observer’s position. The strong, rapidly rotating magnetic field accelerates the electrons and ions in the nebula, which in turn radiate this energy away in the X-ray and optical regions. The charged particles move along the magnetic field lines which produces the polarization of the radiation. This energy flow excites the material in the filaments which in turn re-radiate this energy in the manner typical of emission nebulas.

The Crab nebula has the distinction of being the object which prompted Charles Messier, in 1758, to start his famous list of objects which are ‘not comets’, hence its Messier number of 1. The Crab nebula probably got its name from Lord Rosse in 1844, who was the first to detect the filaments, and referred to them as resembling the legs of a crab. Burnham’s lists the distance to the Crab as 6300 LY, with a diameter of 6 LY. The nebula is expanding at 600 miles/sec which amounts to .2 sec of an arc per year. This is a rather dynamic object by astronomical standards, you could take two pictures 30 years apart and see the expansion.

Visually the nebula is rather small, 4’ x 6’ and rather dim at mag 9. The one time I looked for it, I could not find it with my’6” f5, however the sky was not very dark. Burnham describes it as a fairly easy object in a 3 or 4 inch telescope, which is all Messier had. This makes me wonder why this object caused Messier to make his list, of course 200 years ago, it was smaller and brighter and probably very easy to mistake for a comet. Burnham also notes that it requires a 10” scope to show some detail and a rather large telescope to show the filaments. In my scope I would expect to see a small fuzzy oval.

Roger Tanner 2/3/83
ROGER! You won't believe this, but the crab nebula has just disappeared!!

ROGER? HEY ROGER?!
The Calculating Astronomer

By Kenneth Wilson

This month’s formula will allow you to calculate the theoretical limiting magnitude of your (or any) telescope. All you need to know is the diameter of your telescope’s objective in inches. For you metric fans, 25.4 millimeters = 1 inch.

\[ m = 8.8 + 5 \log D \]

where \( m \) is the limiting magnitude of the telescope and \( D \) is the diameter of the telescope’s objective in inches. So, for example, an 8-inch telescope would have a limiting magnitude of 13.3. Needless to say, all this is based on ideal seeing, conditions, good eyesight, and clean and well aligned optics. The 8.8 constant is derived experimentally, so the combination of your eye, telescope and seeing conditions might do better than this formula predicts or worse. After some field tests, you might want to use this formula in reverse and determine a new constant for your own conditions. In order to check the limiting magnitude of your scope, you might order a set of polar region star charts put out by the American Association of Variable Star Observers (187 Concord Ave., Cambridge, MA 02138) which accurately plot stars and magnitudes down to 15.

P.S. Please note that the above formula is for point source (e.g. stars) objects. Extended objects (i.e. nebulas, galaxies, and comets) will have a limiting magnitude slightly higher than the above formula indicates for any given aperture. Also, up to about 6-inches or so, refractors generally allow a little more light through. This usually gives them a slight fraction of a magnitude fainter limit.

As always, any comments, corrections and suggestions about this column are welcome by the author at: 1750 Clarkston, Apt C, Richmond, VA 23224.
There are two particular velocities which I have, for many years, considered as a special mystery. I had looked upon them as simply belonging to a very large group of subjects which were and would remain beyond my ability to comprehend.

Long, long before I ever considered Astronomy as a hobby, these velocities held a strange fascination for me for some reason. Over the years I have read many books and asked many supposedly knowledgeable people about them. The answers I got were less than satisfying. The books and the “pros” smugly implied that, with a background merely in algebra and trigonometry, it was beyond my ability to comprehend. Anything less than Calculus was inadequate to deal with these mysteries. They could know the answers, but I didn’t belong to their club; I didn’t know Calculus.

On the other side of the coin were the books and “authorities” who talked in such overly-simplified examples that I could find out no more than I already knew, (In the case of some of the “experts”, I suspect that they were nearly as ignorant on the subject as I, but, because of vanity, refused to admit it. Paradoxically, I found one person in this category who held a Masters Degree in Physics! I have long-since discovered that, just because a person has studied a subject, it in no way implies that he UNDERSTANDS it!)

What two velocities have I held in such mysterious awe all these years? (1.) Escape velocity, and (2.) Escape velocities second-cousin, the initial velocity required to raise an object to some particular height above the surface of the Earth (or above the surface of Jupiter, the Moon, the Sun, etc.).

Understanding how to calculate these velocities --- and the MEANING of the calculations --- using only Algebra was of particular interest to me, for then I could figure out such things as: “What is the minimum energy required to travel to the moon?”, or, “If an object escapes Earth, will it fall into orbit about the Sun, or will it travel on forever?”, or, “If an object is in orbit about the Sun, what extra energy --- or velocity --- if necessary to be added, in order to leave the solar system?”. The list goes on and on as to what might be understood for the first time, once a firm grasp of the “what” and “why” of the two mystery velocities has been accomplished.

As for needing Calculus in order to understand and use them, I can now only say ------- BUNK!! I must admit, though, that so as far as I know, a background in Algebra IS needed (At least, I needed to spend a lot of hours mixing and mashing equations before I came to any kind of understanding. If you’re willing, I’ll try my best to explain what I’ve come up with, and how.

Ready? Then with swords raised and pocket calculators at the ready, let’s boldly attack the first subject, Escape velocity.

CHARGE!!!

As a logical beginning, let me slowly work toward a definition of Escape velocity. (I’ll have more than one definition before I’m done.)
If an object is thrown upward from the surface of the Earth, it will, quite naturally, rise to a certain height, stop for an instant, then fall back to the surface of the Earth. The harder you throw it upward, the higher it will rise before falling back to Earth.

There are equations established for easily calculating the height to which an object will rise under these conditions. There is only one thing wrong with these equations; they assume that the force of gravity is the same at all heights. At altitudes near the surface of the Earth, say, up to a mile or so, the equations are accurate enough for general work.

The fact is, the force of gravity does not stay the same as one rises. As I am sure you’re well aware, by Newton’s Law of Universal Gravitation, the force pulling an object toward Earth is proportional to the mass of the object thrown upward and the mass of the Earth. The force is also inversely proportional to the square of the distance between the two objects.

What this means is, as the distance between the two objects increases, the attractive force between the object and the Earth drops off with the SQUARE of the distance between the object and Earth.

Expressed as an equation, it is:

\[
F = \frac{M(1) \cdot M(2)}{D^2}
\]

Where:
- \(M(1)\) equals the mass of the object thrown upward.
- \(M(2)\) equals the mass of the Earth.
- \(D\) equals the distance between them (actually the distance between their “centers-of-mass” which we’ll assume to be their physical center, for this discussion).

Furthermore, the acceleration caused by this force is, by Newton’s second Law, derived from the well known equation:

\[
F = MA
\]

I want to dwell on these two equations for a moment because I think an interesting side-point can be made at this time. Let’s use both equations together and see what force is acting on the Earth, causing it to accelerate toward a ball thrown upward (however slight).

\[
F = M(e) \cdot A
\]

\[
F = \frac{M(b) \cdot M(e)}{D^2}
\]

Where:
- \(M(e)\) is the mass of the Earth
- \(M(b)\) is the mass of the ball
- \(D\) is the distance between their centers.

If we set the equations equal to each other (which they are, since they both equal “\(F\)”):
\[ M(b) \cdot M(e) \]
\[ M(e) \cdot A = \frac{M(b) \cdot M(e)}{D^2} \]

and now solve for “A”, we find that:

\[ A = \frac{M(b)}{D^2} \]

The acceleration of the Earth toward the ball depends solely on the mass of the BALL; not on the mass of the Earth whatsoever. No wonder we can consider the Earth as remaining stationary, even though it, in fact, does accelerate a vanishingly small amount toward the ball.

In the case of the ball, however:

\[ F = M(b) \cdot A \]
\[ F = \frac{M(b) \cdot M(e)}{D^2} \]

\[ M(b) \cdot A = \frac{M(b) \cdot M(e)}{D^2} \]
\[ A = \frac{M(e)}{D^2} \]

The acceleration of the ball toward the earth depends solely on the mass of the Earth, which is considerable, obviously.

At first glance, this may sound as if I’m contradicting Newton’s Third Law about equal and opposite reactions, but I’m not. I am not suggesting that the FORCE on the ball and the Earth are unequal, only the resulting acceleration. In fact, what the equation really tells us is that Galileo was right; all objects fall at the same rate under the influence of Gravity, regardless of their mass.

Now back to the original discussion.

We’ve seen that the force causing the ball to slow its upward velocity and return to the Earth, decreases with the square of the distance between the objects.

An object near the surface of the earth accelerates at a rate of 9.80665 meters/sec^2. The distance between the centers-of-mass is about 6.378(10^6) meters (one Earth-radius).

If we separate the objects by another 6.378(10^6) meters, to a total of two “earth-radii”, the distance will have doubled.

\[ \frac{M(b) \cdot M(a)}{D^2} \]

Since: \( F = \frac{M(b) \cdot M(a)}{D^2} \)
If we double the distance between the two objects, we reduce the force to one-fourth.

\[ D^2 = 2^2 = 4 \]

And so it goes. If we toss the ball up to three “earth-radii”, the downward force on the ball becomes \( \frac{1}{9} \) its original force. The higher the ball is thrown, the less is the force to make it return to the Earth.

Along with the force going down, since:

\[ F = M \cdot A \quad \text{and therefore} \quad A = \frac{F}{M} \]

If the force is reduced to one-fourth its original value so is the rate of acceleration, down to 2.45 meters/sec\(^2\). At three “Earth-radii”, the acceleration toward the Earth would be 1.089 meters/sec\(^2\).

Where does all this tie into Escape velocity? Well, if the acceleration back toward Earth WERE constant, then throwing the ball twice as fast WOULD cause it to go upward twice as high and three times the velocity would cause it to rise to three times the height, etc.

However, as we've seen, the downward acceleration isn't constant, so doubling the initial velocity causes the distance risen to be MORE than double. For every second that passes as the ball is on its upward flight, the force which is slowing it, lessens.

If, for instance, a velocity were given to the ball so as to cause it to rise to a height of, say, 80 miles, and then the original velocity were doubled, rather than only rise to a height of 160 miles, it would actually attain a height of about 350 miles. If the original velocity were tripled, the ball would attain a height of about 900 miles. Beyond this point, the distance really builds rapidly as the original velocity is increased (this distance/velocity relationship will be the subject of a future discussion).

As a final example of the above, if the initial velocity were five times the original, the ball would attain a height of about 4,200 miles.

Again the reason for all this is because the higher the ball rises, the less the downward force there is to slow it down. The ball begins to decelerate the instant we release it, but the rate at which it slows decreases with altitude.

There is a final critical velocity reached where the ball will go on forever, continually slowing, but never quite stopping. Any velocity less than this critical velocity, and the ball will eventually stop and fall back to the Earth (although the distance covered could be, in principle, many light years).

Any velocity greater than this critical velocity and the ball will also go on forever, but it won't slow at quite the same rate. The critical velocity where the ball just barely won't return is called the “Escape velocity”.

Now, all of the previous discussion assumes several simplified things:

1. The ball and the Earth are alone in the universe with no other outside forces acting on either object.
2. The Initial velocity is a result of Ballistic flight. That is, the velocity is attained almost instantly, as compared to a to a rocket with its engines running over long periods or time.

3. The ball has always been thrown upward from the surface of the Earth and not at different heights for different examples.

4. We’re disregarding such things as the motion of the Earth, air resistance, etc.

It might seem that the assumptions are too restrictive. After all, we aren’t alone in the universe and the Earth does move.

The fact is, this “first approximation” is quite close to “real world” definitions of escape velocity. Certainly, it’s close enough for a non-professional.

We could also define Escape velocity a different way, and, in the process we could get our first mathematical insight to Escape velocity, but first I must digress again, in order that the new definition has some significant meaning.

Way back when we were throwing the ball up just a short height we were, without mentioning it, dealing with Kinetic, Potential, and mechanical energy.

Before we threw the ball it was just laying there on the ground, doing nothing important except, maybe waiting for some kids to come along and play with it. (little did it know the important roll it was destined to play In this discussion!). Any energy it had was in the form of Nuclear, chemical, thermal, etc., but it was energy that was just inherent to itself.

When we threw the ball up, however, we added energy to it. (We had to expend energy in order to get it moving and that energy can’t be lost. It was transferred to the ball.)

In the first instant, the ball was, for all practical purposes, still at ground level, but it had its maximum possible velocity. This velocity was the form which the energy took. Energy of motion is called “Kinetic” energy, so our energy was turned into Kinetic energy.

The equation for Kinetic energy is:

\[ E = \frac{1}{2} M V^2 \]

Where:
- \( E \) = energy
- \( M \) = mass of the ball
- \( V \) = velocity of the ball

Now, we have never established which type of system of measurement we’re using (C.G.S., M.K.S., etc.), so, for now, I’ll dust stay with a hypothetical one. In this system, the ball has a mass of one “mass unit”.

Our equation is then:

\[ E = \frac{1}{2} V^2 \]

or simply \( E = \frac{V^2}{2} \)

The velocity at this time is one “velocity unit”, so we have a Kinetic energy of:
\[ E = \frac{1 \cdot 1}{2} = .5 \ E \]

One-half “energy-unit”

This may seem improper to you to just make up units but, I assure you, it is perfectly allowable In Algebra and Physics, (After all wasn’t the M.K.S. system at one time “made up”?)

We know that the ball will immediately begin to slow down, so we must be losing Kinetic energy. Where is it going? Into POTENTIAL energy, or “energy of position”. The idea behind Potential energy is that the higher our ball is raised above the surface of the Earth, the greater is its ability, or potential, to do work when it is allowed to once again fall toward Earth.

As the ball goes higher, it slows. As it slows, more and more Kinetic energy is converted into Potential energy. When the ball finally stops its upward climb, it momentarily stops and ALL the Kinetic energy (.5 energy units) has been transferred into Potential energy. As the ball begins to accelerate toward Earth again, the Potential energy is doing what it is “able” to do, and the Potential energy is again converted into Kinetic energy. (The further it falls, the closer to Earth it gets ---- a loss in Potential energy. Also, the further it falls, the faster it moves---- a gain In Kinetic energy.)

One equation for Potential energy (the one used under our circumstances) is:

\[ E = M \cdot G \cdot D \]

Where:

\[ M = \text{mass of the ball (one mass unit, for us)} \]
\[ G = \text{the force of gravity} \]
\[ D = \text{the distance the ball is from its rest point (the surface of the Earth)} \]

As you can see, the greater the distance separating the ball from the Earth (the higher it is thrown) the greater the potential energy it can attain.

This makes sense, since to get it higher, we need more original Kinetic energy (greater initial velocity).

During all the time the ball is in the air, all the energy is in the form of Kinetic and Potential energy. The TOTAL energy is the same at all times (again .5 energy units).

\[ E (\text{total}) = \text{Kinetic energy} + \text{Potential energy} \]

This total energy is called “Mechanical energy”.

\[ E(m) = E(k) + E(p) \]

Now, in order to be able to convert all the Mechanical energy into Potential energy, the ball obviously has to come to a stop. This brings me back to Escape velocity and a second definition it.

Escape velocity is the maximum Initial velocity where all the initial Kinetic energy can be converted into Potential energy. (The ball would stop at “INFINITY” exactly.)
It is purely a matter of semantics about stopping at “Infinity”, for infinity is neither a place nor a value; It is a CONCEPT. However, if the ball were to stop at any point less than “infinity”, we could argue that it could still go further, so our initial velocity could have been greater.

Since, at the Escape velocity, maximum $E(k)$ can be converted into $E(p)$, then:

$$E(k) \text{ (max)} = E(p) = \text{(max)}$$

$$\frac{M \cdot V^2}{2}$$

Since $E(k) = \frac{M \cdot V^2}{2}$ and $E(p) = M \cdot G \cdot D$

Then when $E(k)$ is maximum:

$$\frac{M \cdot V^2}{2} = M \cdot G \cdot D$$

If we solve for maximum “$V$” (Escape velocity) we get:

$$V^2 = 2 \cdot G \cdot D \quad \text{so, } V = \sqrt{2 \cdot G \cdot D}$$

Where:

- $V =$ Escape velocity
- $G =$ one “$G$” of acceleration
- $D =$ initial distance between the centers-of-mass (one Earth radius)

This particular equation, so I have been led to believe, can be derived by the use of calculus only!

Using this equation, we can use a “normal” system of measurement to determine the Escape velocity from the surface of the Earth. I’ll use the M.K.S. system, since it seems to be so popular these days (although I must confess; I still can only think in miles, pounds, etc. with any comfort. But that’s MY problem; not yours.)

$$V = \sqrt{2 \cdot 9.80665 \times 10^{-3} \text{ km/sec}^2 \cdot 6378 \text{ km}}.$$  

$$V = \sqrt{215.09 \text{ km/sec}^2} = 11.18 \text{ km/sec.} \quad \text{(close enough!!)}$$

There is another unique point about Escape velocity. If an object were to be dropped from some given height above the surface of the Earth, it will continually accelerate toward the Earth and reach a maximum velocity just as it strikes the Earth. If we were to raise the object still higher, and then drop it, the final velocity would be higher. The higher we raise the object before dropping it, the greater will be its final velocity.

There is a “Maximum Final Falling Velocity” for the object, however. If we were to raise the object to the Ultimate Height (which we call “infinity”) the maximum possible velocity it could attain under the influence of gravity would be the Escape velocity.

This is also reasonable if you recall that my latest definition of Escape velocity was the maximum velocity where all the Kinetic energy could be converted into Potential energy. In this case, we’re just reversing the process. We’re starting with the maximum possible potential energy and stating what the maximum Kinetic energy will be.
We could therefore also define Escape velocity as the “Maximum possible falling velocity under the influence of gravity”.

Now that we’ve seen that Escape velocity can be so easily calculated and understood, we can move on to figuring the Escape velocity for other places: the surface of the Sun, Jupiter, and even the extra velocity needed to cause the Earth to be thrown from the firm grasp of the Sun!

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