Fermi Questions: How many piano tuners are there in Chicago?

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Enrico Fermi was arguably the leading theoretical and applied nuclear physicist of the 20th century. His experiments splitting uranium nuclei provided the foundation for the first controlled nuclear fission reactions and the creation of the first atomic bomb. As a part of the Manhattan Project, he was present at the first nuclear test in 1945, named "Trinity," during which he estimated the power of the bomb by seeing how the blast wave moved falling scraps of paper. Although Fermi's estimate of 10 thousand tons of TNT turned out to be lower than the later detailed calculation of 19 kilotons, he was very well-known for his ability to give rough numerical estimates of quantities.

Problems that involve guessing quantities based on very little available information are generally called "Fermi questions." Scientists often turn to making these kinds of back-of-the-envelope estimates before going through longer more detailed calculations, because it can be useful to have some idea of what to expect as a sort of reality check. In some cases, a rough guess is all you want to know.

The classic problem Fermi liked to present to his students as a lecturer was "How many piano tuners are there in Chicago?" Given that a number like this isn't one we can go out and easily look up somewhere, how could this be estimated?

One way to do this is to follow the reasoning outlined below:

1. Start with the fact that the total population is roughly 3 million. (This is something we can easily look up.)
2. Let's assume that typically it's families that own pianos instead of individuals, and there are 4 people in a family on average. That makes about 750,000 families in the city.
3. We know that not every family has a piano though. If we guess that about 1 out of 5 families has a piano, then there are 150,000 pianos to be tuned.
4. How many piano tuners would it take to maintain all of these pianos? If we guess that each piano tuner works on about 4 pianos every weekday, the average piano tuner will have serviced about 1,000 pianos in a year.
5. Since pianos need to be tuned about once a year, there should be about 150 piano tuners in Chicago.

Your assignment:

1. Read Fermi's observation of Trinity in the attached paper.
2. View the list of Fermi problems at the University of Maryland's collection:
   http://www.physics.umd.edu/perg/fermi/fermi.htm
   Choose the 5 questions that interest you the most.

3. Work out your estimate for each of the 5 questions, clearly listing any assumptions used and outlining your line of reasoning.

4. In addition, make up and solve your own Fermi problem.

* Bonus question: How did Fermi estimate the strength of the atomic bomb by dropping shreds of paper?

Some tips and blah blahs: The key to getting accurate estimates is to make careful and realistic assumptions! If you get to the end and start feeling like your estimate is horribly off the mark, try to pinpoint where you might have introduced a bad assumption or think about any relevant assumptions that you might have left out. Also, there's no 'right' way to work out Fermi questions! For the example estimate above, you could have assumed that each tuning costs about \$100 and each tuner needs about \$50,000 a year to find the income sufficient enough to continue this particular career path. This gives an estimate of about 300 tuners, which is only a factor of 2 off from the other answer given above. In most cases, any set of reasonable assumptions will give answers to within one order of magnitude.

My Observations During the Explosion at Trinity on July 16, 1945 — E. Fermi

On the morning of the 16th of July, I was stationed at the Base Camp at Trinity in a position about ten miles from the site of the explosion.

The explosion took place at about 5:30 A.M. I had my face protected by a large board in which a piece of dark welding glass had been inserted. My first impression of the explosion was the very intense flash of light, and a sensation of heat on the parts of my body that were exposed. Although I did not look directly towards the object, I had the impression that suddenly the countryside became brighter than in full daylight. I subsequently looked in the direction of the explosion through the dark glass and could see something that looked like a conglomeration of flames that promptly started rising. After a few seconds the rising flames lost their brightness and appeared as a huge pillar of smoke with an expanded head like a gigantic mushroom that rose rapidly beyond the clouds probably to a height of the order of 30,000 feet. After reaching its full height, the smoke stayed stationary for a while before the wind started dispersing it.

About 40 seconds after the explosion the air blast reached me. I tried to estimate its strength by dropping from about six feet small pieces of paper before, during and after the passage of the blast wave. Since, at the time, there was no wind I could observe very distinctly and actually measure the displacement of the pieces of paper that were in the process of falling while the blast was passing. The shift was about 2½ meters, which, at the time, I estimated to correspond to the blast that would be produced by ten thousand tons of T.N.T.