# A Simple Mathematical Model of Matter–Antimatter Asymmetry Emergence

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**Abstract.** Several very simple models of physical processes of particle annihilation and emergence are constructed demonstrating how natural processes could cause the matter–antimatter asymmetry.

**Keywords**: matter, antimatter, asymmetry, problem, antiparticle, particle, positron, electron

## 1. Introduction

The most popular contemporary cosmological theories explain that our universe emerged some 13.8 billion years in the Big Bang. It is conjectured that this event produced equal amounts of the matter, which consists of particles, and antimatter which consists of antiparticles. When a particle and its antiparticle meet, they annihilate each other disappearing in a burst of light (Feynman, 1987).

Antimatter was first postulated by Arthur Schuster in 1896 and was theoretically discovered by Paul Dirac in 1928, who postulated existence of anti-electrons, later called positrons, based on quantum equation. Physicists did not believe in positrons and mocked at Dirac. In spite of this, positrons were experimentally discovered by Carl Anderson in 1932. For this discovery both Dirac and Anderson got the Nobel Prize.

All contemporary observations and experiments show that the universe we see today is made entirely out of matter while antimatter is extremely rare, i.e., there is a huge number of particles and a tiny amount of antiparticles.. This is one of the greatest mysteries of modern physics. It is called the matter–antimatter asymmetry problem. The challenge for physicists is generating a viable scenario, consistent with observations and experiments, that can give you enough of an excess of matter over antimatter (Canetti, et al., 2012; Siegel, 2019).

Here we suggest several very simple mathematical models of particle annihilation and emergence demonstrating how natural processes could cause this asymmetry. In each process, the transformations of the existing particles and antiparticles go in discrete steps, each of which includes either only collisions and annihilations or emergence of particles and antiparticles

## 2. The MinCol model

Imagine that at some moment of time when elementary particles were only emerging, it was a little accidental asymmetry: there were 12 particles and 10 antiparticles. Some of them collided. A collision between any particle and its antiparticle partner leads to their mutual annihilation, giving rise to various proportions of intense photons (gamma rays) and neutrinos (Feynman, 1987).

Now suppose that the half of particles and antiparticles collide and annihilate one another. At the next moment, the numbers of the remaining particles and antiparticles is doubled, and this process repeats for some time. These two events form the cycle, which is repeated any times.

At first, let us look what happens when the number of collisions is equal to the half of the smallest number of particles/antiparticles. We call this version the **MinCol model**.

Because at the beginning, there were somewhat less antiparticles than particles, the number of the collisions becomes equal to 50% of all antiparticles.

**Moment 1**

There are 12 particles and 10 antiparticles

5 particles/antiparticles annihilate one another

**Moment 2**

There are 7 particles and 5 antiparticles

The remaining particles/antiparticles are doubled

**Moment 3**

There are 14 particles and 10 antiparticles

5 particles/antiparticles annihilate one another

**Moment 4**

There are 9 particles and 5 antiparticles

The remaining particles/antiparticles are doubled

**Moment 5**

There are 18 particles and 10 antiparticles

5 particles/antiparticles annihilate one another

**Moment 6**

There are 13 particles and 5 anti-particles

The remaining particles/antiparticles are doubled

**Moment 7**

There are 26 particles and 10 antiparticles

5 particles/antiparticles annihilate one another

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**Moment 2n + 1**

There are $12 + 2^n$ particles and 10 antiparticles

5 particles/antiparticles annihilate one another

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We see that that according to the MinCol model, the number of antiparticles remains the same while the number of particles grows very fast. It is possible to show that any other asymmetry when the number of particles is larger than the number of antiparticles at the beginning of this process also gives the same result. This shows how a very small accidental asymmetry can grow very fast becoming the matter–antimatter asymmetry in the present universe.

Indeed, physicists estimated that the number of particles in the observable universe is not larger than $10^{81}$. This number is less than $10^{90} = (10^3)^{30} < (2^{10})^{30} = 2^{300}$. It means that it would take less than 300 cycles to get all particles in the observable universe while the number of antiparticles remains the same. In addition, if one cycle is completed in 1 second, then it would take less than 1 hour to get all particles in the observable universe. This brings us to the observable asymmetry in the universe.

## 3. The 40/100 MinCol model

At first, let us look what happens when the number of collisions is equal not to 50% but to approximately 40% of the smallest number of particles/antiparticles while the number of the regeneration (emergence) is still 100% for both particles and antiparticles. We call this version the **40/100 MinCol model**.

Because at the beginning, there were less antiparticles than particles, the number of the collisions at each step becomes (in some cases, approximately) equal to 40% of all existing antiparticles.

**Moment 1**

There are 12 particles and 10 antiparticles.

4 particles/antiparticles annihilate one another.

**Moment 2**

There are 8 particles and 6 antiparticles.

The remaining particles/antiparticles are doubled.

**Moment 3**

There are 16 particles and 12 antiparticles.

4 or 5 particles/antiparticles annihilate one another. For convenience, we take 5 as the number of collisions because it is a better approximation to 40% of the number of antiparticles.

**Moment 4**

There are 11 particles and 7 antiparticles.

The remaining particles/antiparticles are doubled

**Moment 5**

There are 22 particles and 14 antiparticles.

5 or 6 particles/antiparticles annihilate one another. For convenience, we take 6 as the number of collisions because it is a better approximation to 40% of the number of antiparticles.

**Moment 6**

There are 16 particles and 8 antiparticles.

The remaining particles/antiparticles are doubled.

**Moment 7**

There are 32 particles and 16 antiparticles

6 or 7 particles/antiparticles annihilate one another. For convenience, we take 6 as the number of collisions because it is a better approximation to 40% of the number of antiparticles.

**Moment 8**

There are 24 particles and 10 antiparticles.

The remaining particles/antiparticles are doubled.

**Moment 9**

There are 48 particles and 20 antiparticles

8 particles/antiparticles annihilate one another.

**Moment 10**

There are 40 particles and 12 antiparticles.

The remaining particles/antiparticles are doubled.

**Moment 11**

There are 80 particles and 24 antiparticles

9 or 10 particles/antiparticles annihilate one another. For convenience, we take 9 as the number of collisions because it is a better approximation to 40% of the number of antiparticles.

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We see that that according to the 40/100 MinCol model, both numbers of particles and antiparticles grow but the number of particles grows much faster. The ratio of particles to antiparticles grows fast and this means that the matter–antimatter asymmetry grows fast becoming the matter–antimatter asymmetry in the present universe as in the previous model. It is possible to show that any other asymmetry when the number of particles is larger than the number of antiparticles at the beginning of this process also gives the same result.

## 4. The 40/80 MinCol model

At first, let us look what happens when the number of collisions is equal to approximately 40% of the smallest number of particles/antiparticles while now the number of the regeneration (emergence) is additional 80% for both particles and antiparticles. We call this version the **40/80 MinCol model**.

Because at the beginning, there were less antiparticles than particles, the number of the collisions at each step becomes (in some cases, approximately) equal to 40% of all existing antiparticles.

**Moment 1**

There are 12 particles and 10 antiparticles.

4 particles/antiparticles annihilate one another.

**Moment 2**

There are 8 particles and 6 antiparticles.

Additional 80% of the remaining particles/antiparticles emerge (6 particles and 5 antiparticles).

**Moment 3**

There are 14 particles and 11 antiparticles.

4 or 5 particles/antiparticles annihilate one another. For convenience, we take 4 as the number of collisions because it is a better approximation to 40% of the number of antiparticles.

**Moment 4**

There are 10 particles and 7 antiparticles.

Additional 80% of the remaining particles/antiparticles emerge (8 particles and 6 antiparticles).

**Moment 5**

There are 18 particles and 13 antiparticles.

5 or 6 particles/antiparticles annihilate one another. For convenience, we take 5 as the number of collisions because it is a better approximation to 40% of the number of antiparticles.

**Moment 6**

There are 13 particles and 8 antiparticles.

Additional 80% of the remaining particles/antiparticles emerge (10 particles and 6 antiparticles).

**Moment 7**

There are 23 particles and 14 antiparticles

5 or 6 particles/antiparticles annihilate one another. For convenience, we take 6 as the number of collisions because it is a better approximation to 40% of the number of antiparticles.

**Moment 8**

There are 17 particles and 8 antiparticles.

Additional 80% of the remaining particles/antiparticles emerge (14 particles and 6 antiparticles).

**Moment 9**

There are 31 particles and 14 antiparticles

5 or 6 particles/antiparticles annihilate one another. For convenience, we take 6 as the number of collisions because it is a better approximation to 40% of the number of antiparticles.

**Moment 10**

There are 25 particles and 8 antiparticles.

Additional 80% of the remaining particles/antiparticles emerge (20 particles and 6 antiparticles).

**Moment 11**

There are 45 particles and 14 antiparticles

5 or 6 particles/antiparticles annihilate one another. For convenience, we take 6 as the number of collisions because it is a better approximation to 40% of the number of antiparticles.

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We see that that according to the 40/80 MinCol model, the number of particles still grows but the number of antiparticles cannot be larger than 14 because it is locked in the cycle

$$10 \to 6 \to 11 \to 7 \to 13 \to 8 \rightleftarrows 14$$

As the number of particles grows rather fast, this means that the matter–antimatter asymmetry grows becoming the matter–antimatter asymmetry in the present universe as in the MinCol model. It is possible to show that any other asymmetry when the number of particles is larger than the number of antiparticles at the beginning of this process also gives the same result.

## 5. A probabilistic MinCol model

At first, let us look what happens when the number of collisions has some probability distribution with respect to the smallest number of particles/antiparticles. We call this version a **probabilistic MinCol model**. Assuming that the process is a Markov chain, i.e., the probability distribution depends only on the state but not on the previous history, we derive the resulting state as the expectation of the performed transformation.

We take the following distribution of the events:

- The probability $p(0.6)$ the number of collisions is equal to approximately equal to 60% of the smallest number of particles/antiparticles is 0.25.

- The probability $p(0.5)$ the number of collisions is equal to approximately equal to 50% of the smallest number of particles/antiparticles is 0.5.
- The probability $p(0.4)$ the number of collisions is equal to approximately equal to 40% of the smallest number of particles/antiparticles is 0.25.

For simplicity, we assume that at the next moment after collision and annihilation, the numbers of the remaining particles and antiparticles is doubled, and this process repeats for some time. These two events form the cycle, which is repeated any times.

Let us find expectation of the number of collisions and annihilations. We have

$$E = 0.6 \cdot 0.25 + 0.5 \cdot 0.5 + 0.4 \cdot 0.25 = 0.15 + 0.25 + 0.1 = 0.5$$

It means if the lesser number of particles and antiparticles is $n$, then approximately half of this number of particles collides with antiparticles and all of them are annihilated.

Because at the beginning, there were less antiparticles than particles, the number of the collisions at each step becomes (in some cases, approximately) equal to 50% of all existing antiparticles.

**Moment 1**

There are 12 particles and 10 antiparticles

5 particles/antiparticles annihilate one another

**Moment 2**

There are 7 particles and 5 antiparticles

The remaining particles/antiparticles are doubled

**Moment 3**

There are 14 particles and 10 antiparticles

5 particles/antiparticles annihilate one another

**Moment 4**

There are 9 particles and 5 antiparticles

The remaining particles/antiparticles are doubled

**Moment 5**

There are 18 particles and 10 antiparticles

5 particles/antiparticles annihilate one another

**Moment 6**

There are 13 particles and 5 anti-particles

The remaining particles/antiparticles are doubled

**Moment 7**

There are 26 particles and 10 antiparticles

5 particles/antiparticles annihilate one another

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**Moment 2n + 1**

There are $12 + 2^n$ particles and 10 antiparticles

5 particles/antiparticles annihilate one another

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We see that that according to the probabilistic MinCol model, the number of antiparticles remains the same while the number of particles grows very fast. It is possible to show that any other asymmetry when the number of particles is larger than the number of antiparticles at the beginning of this process also gives the same result. This shows how a very small accidental asymmetry can grow very fast becoming the matter–antimatter asymmetry in the present universe.

## 6. The MaxCol model

Now let us look how the process goes when the number of collisions is equal to the 40% of the largest number of particles/antiparticles. We call this version the **MaxCol model**.

**Moment 1**

There are 12 particles and 10 antiparticles

6 particles/antiparticles annihilate one another

**Moment 2**

There are 6 particles and 4 antiparticles

The remaining particles/antiparticles are doubled

**Moment 3**

There are 12 particles and 8 antiparticles

6 particles/antiparticles annihilate one another

**Moment 4**

There are 6 particles and 2 antiparticles

The remaining particles/antiparticles are doubled

**Moment 5**

There are 12 particles and 4 antiparticles

4 particles/antiparticles annihilate one another

**Moment 6**

No antiparticles

We see that in the MaxCol model, antiparticles completely disappear very fast. If antiparticles can be spontaneously generated (can spontaneously emerge), this brings us to the observable asymmetry in the universe.

It is possible to show that any other asymmetry when the number of particles is larger than the number of antiparticles at the beginning of this process also gives the same result.

## 7. Conclusion

Although being very simplified, the constructed models of particle annihilation and emergence demonstrate the general tendency of such natural processes to create a huge asymmetry between particles and antiparticles due to a tiny accidental difference between them at the beginning of the process.

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