

1
00:00:00,000 --> 00:00:04,318
physics that's usually not appreciate

2
00:00:01,469 --> 00:00:06,359
even by people that you know get degrees

3
00:00:04,318 --> 00:00:08,429
in physics are not necessarily quantum

4
00:00:06,359 --> 00:00:10,199
experts you know but they have spent

5
00:00:08,429 --> 00:00:12,570
quite a bit of time studying quantum

6
00:00:10,199 --> 00:00:14,099
physics it's sometimes not really

7
00:00:12,570 --> 00:00:16,138
appreciated that the wave function is

8
00:00:14,099 --> 00:00:17,278
the same thing as the the particle that

9
00:00:16,138 --> 00:00:19,618
ultimately comes out of a measurement

10
00:00:17,278 --> 00:00:21,509
and we cause the atom and it's wave

11
00:00:19,618 --> 00:00:23,129
function of the same thing and Adam can

12
00:00:21,510 --> 00:00:24,480
be in two places at once or three or

13
00:00:23,129 --> 00:00:26,910
four or actually an infinite number of

14
00:00:24,480 --> 00:00:28,260
places at once the observation

15
00:00:26,910 --> 00:00:33,270
collapsing the wave function is what

16
00:00:28,260 --> 00:00:36,149
creates literally creates the atom now

17
00:00:33,270 --> 00:00:38,910
let's give an example of the weirdness

18
00:00:36,149 --> 00:00:41,070
of a quantum measurement let's take this

19
00:00:38,909 --> 00:00:43,500
is a penny and you can slice this penny

20
00:00:41,070 --> 00:00:47,128
two ways you can slice the penny down

21
00:00:43,500 --> 00:00:48,659
the right down the middle and you can

22
00:00:47,128 --> 00:00:50,669
get the Lincoln on the front and the

23
00:00:48,659 --> 00:00:53,488
memorial on the back or you could call

24
00:00:50,670 --> 00:00:54,989
this thing chopping the penny in half

25
00:00:53,488 --> 00:00:56,009
where you have the top half the penny in

26
00:00:54,988 --> 00:00:58,439
the bottom half of the pennies all

27
00:00:56,009 --> 00:01:00,750
called as a slice I'll call this a chop

28
00:00:58,439 --> 00:01:03,299
for the experiment the thought

29

00:01:00,750 --> 00:01:05,819
experiment assume we have a mutual

30
00:01:03,299 --> 00:01:09,569
friend called Niels miss for fun column

31
00:01:05,819 --> 00:01:11,759
Niels you might know why maybe he has

32
00:01:09,569 --> 00:01:13,978
two machines that sliced chop and mail

33
00:01:11,760 --> 00:01:15,570
out pennies one machine is labeled

34
00:01:13,978 --> 00:01:17,969
classical in the others label quantum

35
00:01:15,569 --> 00:01:20,129
now when he sets the classical machine

36
00:01:17,969 --> 00:01:22,079
to slice the cut is parallel through the

37
00:01:20,129 --> 00:01:23,640
penny so that you wind up with two thin

38
00:01:22,079 --> 00:01:25,259
coins one is Lincoln on one side the

39
00:01:23,640 --> 00:01:27,450
other has linked in the memorial on on

40
00:01:25,259 --> 00:01:29,700
the other side when he sets the

41
00:01:27,450 --> 00:01:31,290
classical machine to chop the chop is

42
00:01:29,700 --> 00:01:33,659
perpendicular to the penny resulting in

43
00:01:31,290 --> 00:01:34,740

to half moon shape at penneys wonderful

44

00:01:33,659 --> 00:01:37,350
Lincoln's head the other blinking

45

00:01:34,739 --> 00:01:40,199
shoulders so now he takes the two sliced

46

00:01:37,349 --> 00:01:44,009
penny so the two the two sliced pennies

47

00:01:40,200 --> 00:01:45,810
on the top it takes those and puts one

48

00:01:44,009 --> 00:01:47,640
an envelope label sliced pennies and

49

00:01:45,810 --> 00:01:50,700
emails one envelope to you and one to me

50

00:01:47,640 --> 00:01:53,189
I opened my envelope and I find a thin

51

00:01:50,700 --> 00:01:55,049
penny with Lincoln on it so i can safely

52

00:01:53,188 --> 00:01:56,789
infer that your envelope contains a thin

53

00:01:55,049 --> 00:01:58,500
cutting with a lincoln lincoln memorial

54

00:01:56,790 --> 00:02:00,659
on one side and sure enough when you

55

00:01:58,500 --> 00:02:03,060
open your envelope you're going to see

56

00:02:00,659 --> 00:02:05,729
if I have this and my envelope you'll

57

00:02:03,060 --> 00:02:07,649
have that one all right well now my

58
00:02:05,728 --> 00:02:08,909
friend Niels takes the 2 chopped pennies

59
00:02:07,649 --> 00:02:11,068
it puts one in each envelope labeled

60
00:02:08,909 --> 00:02:13,859
chopped pennies again emails one to you

61
00:02:11,068 --> 00:02:16,169
and one to me now I open my own flow

62
00:02:13,860 --> 00:02:17,790
when I find a penny with Lincoln's head

63
00:02:16,169 --> 00:02:19,829
in it so this is what's in my honey and

64
00:02:17,789 --> 00:02:22,349
sure enough I guess that you're going to

65
00:02:19,830 --> 00:02:23,850
find the bottom half of the coin in

66
00:02:22,349 --> 00:02:25,650
yours and that's indeed what you find

67
00:02:23,849 --> 00:02:28,259
all right no big mystery here kind of

68
00:02:25,650 --> 00:02:30,780
boring now one day I get an envelope

69
00:02:28,259 --> 00:02:32,129
with the word quantum written on it and

70
00:02:30,780 --> 00:02:34,770
I figured this might be important so I

71
00:02:32,129 --> 00:02:36,629
call Neil's and I ask Niels what do I

72
00:02:34,770 --> 00:02:39,240
have do I have a sliced penny or a

73
00:02:36,629 --> 00:02:41,219
chopped penny and he says well this time

74
00:02:39,240 --> 00:02:42,930
I use the quantum machine on this one

75
00:02:41,219 --> 00:02:46,919
not the classical machine so it's your

76
00:02:42,930 --> 00:02:48,780
choice I say oh well what do you mean

77
00:02:46,919 --> 00:02:50,789
you've already sliced or chopped opinion

78
00:02:48,780 --> 00:02:53,099
mail it to me I've got it in my hands

79
00:02:50,789 --> 00:02:55,379
how can i change that now he says well

80
00:02:53,099 --> 00:02:58,169
the quantum machine is special it

81
00:02:55,379 --> 00:03:00,359
processes penny it males out the pairs

82
00:02:58,169 --> 00:03:02,759
and unlabeled envelopes without anybody

83
00:03:00,360 --> 00:03:04,440
looking at the pennies the process does

84
00:03:02,759 --> 00:03:08,039
not get turned into a slice or a chop

85
00:03:04,439 --> 00:03:09,900
until somebody looks at the coin do you

86

00:03:08,039 --> 00:03:12,000
mean to say I asked that I can decide

87
00:03:09,900 --> 00:03:13,860
whether I've got a sliced penny or a

88
00:03:12,000 --> 00:03:16,610
chopped penny and out that envelope and

89
00:03:13,860 --> 00:03:19,290
magically I will get one or the other

90
00:03:16,610 --> 00:03:21,540
that's correct saz Neil's and danish and

91
00:03:19,289 --> 00:03:22,889
as soon as you open the envelope and

92
00:03:21,539 --> 00:03:24,359
look at whether you've got a sliced

93
00:03:22,889 --> 00:03:26,819
penny or a chopped can you guess what

94
00:03:24,360 --> 00:03:29,070
the other half the correct other half

95
00:03:26,819 --> 00:03:32,159
will be what your buddy over there is

96
00:03:29,069 --> 00:03:33,870
going to have in his envelope but I say

97
00:03:32,159 --> 00:03:35,699
it's already been sliced or chopped he

98
00:03:33,870 --> 00:03:37,140
says no the quantum machine only does

99
00:03:35,699 --> 00:03:40,199
that part of the joint as part of the

100
00:03:37,139 --> 00:03:41,729

job it correlates the two halves but it

101

00:03:40,199 --> 00:03:43,919

takes your consciousness to complete the

102

00:03:41,729 --> 00:03:45,329

process you get to decide which way the

103

00:03:43,919 --> 00:03:48,869

penny has been have when you open the

104

00:03:45,330 --> 00:03:51,330

envelope now this very same thing can be

105

00:03:48,870 --> 00:03:54,269

done of course not with real pennies but

106

00:03:51,330 --> 00:03:56,190

it can be done with with quantum objects

107

00:03:54,269 --> 00:03:57,539

such as photons yes I'm going to talk

108

00:03:56,189 --> 00:04:00,060

about next I'm going to talk about the

109

00:03:57,539 --> 00:04:01,769

bell in equality and more importantly a

110

00:04:00,060 --> 00:04:03,299

new inequality that you might never have

111

00:04:01,769 --> 00:04:05,519

heard of called the Leggett inequality

112

00:04:03,299 --> 00:04:07,890

that was recently measured it was

113

00:04:05,519 --> 00:04:10,890

actually formulated almost 30 years ago

114

00:04:07,889 --> 00:04:13,139

by a professor Leggett who was a

115
00:04:10,889 --> 00:04:14,879
Nobel Prize winner but it wasn't tested

116
00:04:13,139 --> 00:04:16,829
until about a year and a half ago when

117
00:04:14,879 --> 00:04:18,358
an article appeared in nature that a

118
00:04:16,829 --> 00:04:19,949
measurement was made by this prominent

119
00:04:18,358 --> 00:04:22,079
quantum optics group in at the

120
00:04:19,949 --> 00:04:23,909
University of Vienna read by led by

121
00:04:22,079 --> 00:04:25,500
Anton Zeilinger in which they measured

122
00:04:23,910 --> 00:04:27,600
the legged inequality which actually

123
00:04:25,500 --> 00:04:29,370
goes a step deeper than the bell one

124
00:04:27,600 --> 00:04:31,290
rules out any possible interpretation

125
00:04:29,370 --> 00:04:35,639
other than that consciousness creates

126
00:04:31,290 --> 00:04:38,520
reality when the measurement is made now

127
00:04:35,639 --> 00:04:40,050
in the quantum enigma of course you

128
00:04:38,519 --> 00:04:41,789
don't have coins but you have twin state

129
00:04:40,050 --> 00:04:44,069
photons that don't have any particular

130
00:04:41,790 --> 00:04:46,110
polarization until their polarization

131
00:04:44,069 --> 00:04:47,790
one of them is measured so twin state

132
00:04:46,110 --> 00:04:49,680
photons can be entangled in a state of

133
00:04:47,790 --> 00:04:51,420
identical polarization but really have

134
00:04:49,680 --> 00:04:53,250
no particular polarization until you

135
00:04:51,420 --> 00:04:54,840
measure it it's the observation of the

136
00:04:53,250 --> 00:04:58,589
polarization of one of the photons as

137
00:04:54,839 --> 00:05:00,509
being say vertical or horizontal that

138
00:04:58,589 --> 00:05:02,819
instantaneously collapses both photons

139
00:05:00,509 --> 00:05:04,259
to vertical visit polarizations and

140
00:05:02,819 --> 00:05:06,149
that's true when they fly apart you

141
00:05:04,259 --> 00:05:07,649
create a pair of photons one flies this

142
00:05:06,149 --> 00:05:09,449
way one flies that way I make a

143

00:05:07,649 --> 00:05:11,819
measurement over here that measurement

144
00:05:09,449 --> 00:05:13,469
and the kind of measurement I make is

145
00:05:11,819 --> 00:05:15,300
determined by what I decide over here

146
00:05:13,470 --> 00:05:17,040
that measurement will then be reflected

147
00:05:15,300 --> 00:05:18,750
in what this coin over here is going to

148
00:05:17,040 --> 00:05:20,100
do even though they're flying a part of

149
00:05:18,750 --> 00:05:23,279
the speed of light can't communicate

150
00:05:20,100 --> 00:05:25,050
with each other quantum probability is

151
00:05:23,279 --> 00:05:27,089
not the probability of where the atom is

152
00:05:25,050 --> 00:05:29,189
or where a photon is it is the objective

153
00:05:27,089 --> 00:05:32,039
probability of where you will find it

154
00:05:29,189 --> 00:05:34,139
the atom was not in the box if the box

155
00:05:32,040 --> 00:05:35,580
is where the atom is the item was not in

156
00:05:34,139 --> 00:05:38,159
the box before you observed it to be

157
00:05:35,579 --> 00:05:40,409

there and Heisenberg had this to say is

158

00:05:38,160 --> 00:05:42,060

the runner Heisenberg's words but the

159

00:05:40,410 --> 00:05:44,610

atom or elementary particles are not

160

00:05:42,060 --> 00:05:46,889

real they form a world of potentialities

161

00:05:44,610 --> 00:05:51,509

or possibilities rather than one effects

162

00:05:46,889 --> 00:05:55,649

or things or facts let's look at the

163

00:05:51,509 --> 00:05:58,889

bell inequality if you have a quantum

164

00:05:55,649 --> 00:06:00,659

object that has a spin then you can

165

00:05:58,889 --> 00:06:02,639

choose to measure the spin in any given

166

00:06:00,660 --> 00:06:04,140

direction and what you'll find is that

167

00:06:02,639 --> 00:06:06,419

whatever direction you choose as spin is

168

00:06:04,139 --> 00:06:07,860

going to be either up or down by up I

169

00:06:06,420 --> 00:06:09,240

mean if it's spinning like this the

170

00:06:07,860 --> 00:06:11,550

access points up it is spinning like

171

00:06:09,240 --> 00:06:13,620

that the access points down so you have

172
00:06:11,550 --> 00:06:15,420
actually have two particles that are

173
00:06:13,620 --> 00:06:16,769
entangled with each other and I'll tell

174
00:06:15,420 --> 00:06:18,660
you in a second why we have two instead

175
00:06:16,769 --> 00:06:20,849
of one so one of them flies off in one

176
00:06:18,660 --> 00:06:22,920
direction i choose to measure its spin

177
00:06:20,850 --> 00:06:25,530
say in this direction and call that

178
00:06:22,920 --> 00:06:27,240
direction a so i measure that now there

179
00:06:25,529 --> 00:06:29,789
are also two other directions I could

180
00:06:27,240 --> 00:06:31,319
measure B and C they're arbitrary I can

181
00:06:29,790 --> 00:06:32,340
choose them in a anyway I want to but

182
00:06:31,319 --> 00:06:34,139
there are two other possible directions

183
00:06:32,339 --> 00:06:36,060
I could measure but having measured this

184
00:06:34,139 --> 00:06:38,250
one direction quantum theory says I

185
00:06:36,060 --> 00:06:39,569
can't measure the second one but I can

186
00:06:38,250 --> 00:06:41,430
measure the second one indirectly

187
00:06:39,569 --> 00:06:43,980
because if the two particles were in 10

188
00:06:41,430 --> 00:06:46,379
it's partner over here is guaranteed to

189
00:06:43,980 --> 00:06:47,850
have the opposite spin sometimes the

190
00:06:46,379 --> 00:06:49,560
same sometimes the opposite depending on

191
00:06:47,850 --> 00:06:51,300
which which which kind of particle you

192
00:06:49,560 --> 00:06:52,800
choose let's assume it's exactly the

193
00:06:51,300 --> 00:06:54,360
opposite spin now I can make a

194
00:06:52,800 --> 00:06:55,889
measurement on this one in some other

195
00:06:54,360 --> 00:06:58,500
directions I'm second direction call it

196
00:06:55,889 --> 00:07:00,719
be and I know then that if I measure

197
00:06:58,500 --> 00:07:03,120
this one to be in that direction then

198
00:07:00,720 --> 00:07:04,470
this one over here would be in this one

199
00:07:03,120 --> 00:07:06,269
the opposite direction so I've

200

00:07:04,470 --> 00:07:08,160
determined two directions for this

201
00:07:06,269 --> 00:07:09,750
particle over here by virtue of a direct

202
00:07:08,160 --> 00:07:11,780
measurement by virtue of a measurement

203
00:07:09,750 --> 00:07:14,040
of its partner in a different direction

204
00:07:11,779 --> 00:07:19,500
so i can write out these probabilities

205
00:07:14,040 --> 00:07:21,810
the probability of measuring probability

206
00:07:19,500 --> 00:07:24,120
of measuring say spin up in Direction a

207
00:07:21,810 --> 00:07:25,740
and spin down and direction b is the

208
00:07:24,120 --> 00:07:28,379
probability measuring spin up in

209
00:07:25,740 --> 00:07:29,850
direction a down in direction b+

210
00:07:28,379 --> 00:07:32,040
indirection see which i don't know which

211
00:07:29,850 --> 00:07:34,590
i never measured and again the plus the

212
00:07:32,040 --> 00:07:37,710
probability of spin up being positive in

213
00:07:34,589 --> 00:07:39,810
a down in B and in the other direction

214
00:07:37,709 --> 00:07:41,969

and see and as you with a little bit of

215

00:07:39,810 --> 00:07:48,480

mathematical manipulation you can show

216

00:07:41,970 --> 00:07:50,430

that this plus that equals that one plus

217

00:07:48,480 --> 00:07:52,200

something and the fact of the matter is

218

00:07:50,430 --> 00:07:53,400

that something is positive it's always

219

00:07:52,199 --> 00:07:55,469

got to be positive you can't have

220

00:07:53,399 --> 00:07:58,259

negative probabilities therefore this

221

00:07:55,470 --> 00:08:01,440

equation leads to an inequality that the

222

00:07:58,259 --> 00:08:05,310

spin in this direction a and direction B

223

00:08:01,439 --> 00:08:06,689

plus the spin in direction B and C it

224

00:08:05,310 --> 00:08:09,089

has to be greater than or equal to the

225

00:08:06,689 --> 00:08:11,639

spin and direction AC so this is the

226

00:08:09,089 --> 00:08:13,979

bell inequality this is what's predicted

227

00:08:11,639 --> 00:08:17,310

if particles have an intrinsic spin

228

00:08:13,980 --> 00:08:21,960

before you look at them now as it turns

229
00:08:17,310 --> 00:08:24,420
out quantum physics has a rule that says

230
00:08:21,959 --> 00:08:26,819
that if you take the spins in two

231
00:08:24,420 --> 00:08:28,860
different directions now this is the

232
00:08:26,819 --> 00:08:32,730
this is the formula that tells you what

233
00:08:28,860 --> 00:08:33,899
the probability is a finding the if you

234
00:08:32,730 --> 00:08:36,480
have a whole distribution of particles

235
00:08:33,899 --> 00:08:38,850
finding some fraction of them separated

236
00:08:36,480 --> 00:08:40,830
by some angle θ as it turns out if

237
00:08:38,850 --> 00:08:43,230
you put this formula into the bell

238
00:08:40,830 --> 00:08:46,020
inequality the beltline equality is

239
00:08:43,230 --> 00:08:47,909
violated Bell inequality is not true and

240
00:08:46,019 --> 00:08:50,429
the bell inequality is based upon the

241
00:08:47,909 --> 00:08:52,409
idea that spin is something that's

242
00:08:50,429 --> 00:08:53,909
intrinsic that's that's not dependent

243
00:08:52,409 --> 00:08:55,199
upon your measuring it but it's there

244
00:08:53,909 --> 00:08:57,269
all along and you

245
00:08:55,200 --> 00:08:59,040
choose to measure it so it's there when

246
00:08:57,269 --> 00:09:01,110
the particles were were joined together

247
00:08:59,039 --> 00:09:03,089
when they were made to fly apart there's

248
00:09:01,110 --> 00:09:04,590
the the spins in the different

249
00:09:03,090 --> 00:09:06,240
directions are inherent to the particles

250
00:09:04,590 --> 00:09:08,720
and when you choose to measure over here

251
00:09:06,240 --> 00:09:11,789
that's fine and this one's going to be

252
00:09:08,720 --> 00:09:14,160
an anti was going to be in the opposite

253
00:09:11,789 --> 00:09:16,230
direction for any given spin because

254
00:09:14,159 --> 00:09:17,519
they were they were entangled here but

255
00:09:16,230 --> 00:09:19,500
really those spins belong to the

256
00:09:17,519 --> 00:09:21,149
particles and your measurement is like a

257

00:09:19,500 --> 00:09:23,460
classical thing you look at something

258
00:09:21,149 --> 00:09:25,019
objectively you measure what it is but

259
00:09:23,460 --> 00:09:26,730
in fact the fact that the belly

260
00:09:25,019 --> 00:09:29,850
inequality is violated and the quantum

261
00:09:26,730 --> 00:09:31,289
rule is followed implies that that spin

262
00:09:29,850 --> 00:09:34,170
is not really there until you make it

263
00:09:31,289 --> 00:09:36,419
happen the spin in a given direction is

264
00:09:34,169 --> 00:09:38,849
created by your deciding to measure that

265
00:09:36,419 --> 00:09:42,870
direction and then that requires that

266
00:09:38,850 --> 00:09:45,060
its partner will be the in the opposite

267
00:09:42,870 --> 00:09:46,950
direction for that spin measurement and

268
00:09:45,059 --> 00:09:48,509
have its own angle of spin in a

269
00:09:46,950 --> 00:09:51,120
different direction which then this one

270
00:09:48,509 --> 00:09:52,620
would have so the bell inequality is

271
00:09:51,120 --> 00:09:54,509

telling us or the violation of the bell

272

00:09:52,620 --> 00:09:58,279

inequality is telling us that it's the

273

00:09:54,509 --> 00:10:01,730

observation that's creating the reality

274

00:09:58,279 --> 00:10:01,730

now as it turns