

1
00:00:00,000 --> 00:00:02,417
(soft music)

2
00:00:09,080 --> 00:00:09,913
– Hi everyone.

3
00:00:09,913 --> 00:00:13,160
And welcome back to
Conversations at the Perimeter.

4
00:00:13,160 --> 00:00:13,993
I'm Lauren.

5
00:00:13,993 --> 00:00:15,250
– And I'm Colin.

6
00:00:15,250 --> 00:00:16,450
– And today we're bringing you

7
00:00:16,450 --> 00:00:18,780
a conversation with Meenu Kumari,

8
00:00:18,780 --> 00:00:21,820
a post-doctoral researcher
here at Perimeter Institute

9
00:00:21,820 --> 00:00:24,620
who specializes in quantum chaos.

10
00:00:24,620 --> 00:00:25,650
– Quantum chaos.

11
00:00:25,650 --> 00:00:26,483
You know, that's a term

12
00:00:26,483 --> 00:00:28,460
that I actually haven't encountered before

13

00:00:28,460 --> 00:00:30,240
our conversation with Meenu,

14

00:00:30,240 --> 00:00:32,310
despite talking to a lot
of theoretical physicists,

15

00:00:32,310 --> 00:00:35,850
that, that idea of quantum
chaos was, was new to me.

16

00:00:35,850 --> 00:00:38,053
And I was fascinated to
hear about it because

17

00:00:38,053 --> 00:00:39,430
when I first heard it, honestly,

18

00:00:39,430 --> 00:00:42,400
it sounds a bit like something
outta science fiction.

19

00:00:42,400 --> 00:00:44,190
– Well, Meenu has actually
been a friend of mine

20

00:00:44,190 --> 00:00:45,500
for many years now,

21

00:00:45,500 --> 00:00:47,830
but I still learned a lot
from this conversation

22

00:00:47,830 --> 00:00:50,920
about her life, her journey
to where she is today

23

00:00:50,920 --> 00:00:54,120
and her research in the quantum

to classical correspondence

24

00:00:54,120 --> 00:00:55,940

and really studying how we can move

25

00:00:55,940 --> 00:00:58,820

between these quantum

and classical realms.

26

00:00:58,820 --> 00:01:00,650

So without further ado,

27

00:01:00,650 --> 00:01:03,083

let's dive right into the quantum chaos.

28

00:01:07,005 --> 00:01:07,838

– Meenu Kumari.

29

00:01:07,838 --> 00:01:10,960

Thank you so much for joining

us here at Perimeter Institute

30

00:01:10,960 --> 00:01:13,470

in our, in our beautiful

but empty theater.

31

00:01:13,470 --> 00:01:14,620

Thanks for joining us.

32

00:01:14,620 --> 00:01:16,174

– Thanks a lot for having me.

33

00:01:16,174 --> 00:01:17,350

– So Meenu, thank you so much

34

00:01:17,350 --> 00:01:18,730

for sitting down with us today.

35

00:01:18,730 --> 00:01:21,150
I'm really excited to talk to you.

36
00:01:21,150 --> 00:01:24,230
Maybe you can just start by
telling us what you do here

37
00:01:24,230 --> 00:01:25,720
at Perimeter, what your role is,

38
00:01:25,720 --> 00:01:28,660
and also what you're
interested in studying.

39
00:01:28,660 --> 00:01:31,940
– I'm a postdoc in the quantum
information research group

40
00:01:31,940 --> 00:01:33,250
at Perimeter.

41
00:01:33,250 --> 00:01:36,350
I joined in September, 2019,

42
00:01:36,350 --> 00:01:41,350
and I did my PhD at IQC at
the University of Waterloo

43
00:01:41,550 --> 00:01:45,103
from September, 2014 to August, 2019.

44
00:01:45,953 --> 00:01:48,860
– So IQC, that's the Institute
for quantum computing,

45
00:01:48,860 --> 00:01:50,600
just down the road from here.

46
00:01:50,600 --> 00:01:54,320

So is quantum computing
part of, of what you do?

47

00:01:54,320 --> 00:01:55,877

You're a theorist.

– Yeah.

48

00:01:55,877 --> 00:01:59,270

– And quantum computing
sounds like it's for machines.

49

00:01:59,270 --> 00:02:00,620

So can you explain

50

00:02:00,620 --> 00:02:02,950

how you're connected to quantum computing?

51

00:02:02,950 --> 00:02:04,200

– My field,

52

00:02:04,200 --> 00:02:07,540

my research is in the field
of quantum information,

53

00:02:07,540 --> 00:02:10,350

using the tools and techniques
of quantum information

54

00:02:10,350 --> 00:02:13,580

to study other questions in physics.

55

00:02:13,580 --> 00:02:14,413

The thing is

56

00:02:15,680 --> 00:02:18,060

quantum computing uses

57

00:02:18,060 --> 00:02:21,050

quantum information techniques

58
00:02:21,050 --> 00:02:23,230
or for quantum processing techniques

59
00:02:23,230 --> 00:02:27,050
to build like quantum computer,

60
00:02:27,050 --> 00:02:28,750
like so many tools

61
00:02:28,750 --> 00:02:30,080
and techniques have been developed

62
00:02:30,080 --> 00:02:31,490
in the field of quantum information,

63
00:02:31,490 --> 00:02:33,200
which can be used

64
00:02:33,200 --> 00:02:34,460
in other fields of physics,

65
00:02:34,460 --> 00:02:35,450
like high energy physics,

66
00:02:35,450 --> 00:02:36,690
or (mumbles) metaphysics

67
00:02:37,570 --> 00:02:39,430
to study other questions.

68
00:02:39,430 --> 00:02:41,400
So quantum information is basically

69
00:02:41,400 --> 00:02:42,370
like

70

00:02:42,370 --> 00:02:44,853
world is fundamentally quantum, right?

71
00:02:44,853 --> 00:02:45,686
If you--
- Oh, so,

72
00:02:45,686 --> 00:02:47,710
just to interrupt the world
is fundamentally quantum

73
00:02:47,710 --> 00:02:49,070
in the sense that

74
00:02:49,070 --> 00:02:50,600
at the underneath everything,

75
00:02:50,600 --> 00:02:53,770
quantum mechanics sort of describes how,

76
00:02:53,770 --> 00:02:56,170
how the world works at this small level.

77
00:02:56,170 --> 00:02:57,910
If you dig deep enough into anything

78
00:02:57,910 --> 00:02:59,250
you'll get into the quantum realm.

79
00:02:59,250 --> 00:03:01,310
Is that fair?

80
00:03:01,310 --> 00:03:02,143
- Yeah.

81
00:03:02,143 --> 00:03:03,740
So the thing is like

82

00:03:03,740 --> 00:03:06,270
first classical physics was developed,

83
00:03:06,270 --> 00:03:08,040
which is like Newtonian mechanics,

84
00:03:08,040 --> 00:03:09,350
Galilean relativity

85
00:03:09,350 --> 00:03:12,710
and then Hamiltonian mechanics and so on.

86
00:03:12,710 --> 00:03:16,250
So those theories describe the world

87
00:03:16,250 --> 00:03:18,420
at the macroscopic level

88
00:03:18,420 --> 00:03:20,010
very well, actually.

89
00:03:20,010 --> 00:03:22,240
But towards the end of 18th century,

90
00:03:22,240 --> 00:03:24,440
like around 1890 or something,

91
00:03:24,440 --> 00:03:27,360
there were so many phenomena that,

92
00:03:27,360 --> 00:03:30,320
that we are discovered
experimentally, which,

93
00:03:30,320 --> 00:03:31,230
which were not,

94
00:03:31,230 --> 00:03:33,050

which the physicists
were not able to explain

95

00:03:33,050 --> 00:03:34,566
using the Mecca,

96

00:03:34,566 --> 00:03:37,170
using the formulation
of classical physics.

97

00:03:37,170 --> 00:03:39,745
So they started to dig
into what's going on,

98

00:03:39,745 --> 00:03:41,570
trying to understand, for example,

99

00:03:41,570 --> 00:03:42,900
for the photo electric effect.

100

00:03:42,900 --> 00:03:44,920
Around 1920 to 1930,

101

00:03:44,920 --> 00:03:48,880
this new formalism of quantum
mechanics was developed.

102

00:03:48,880 --> 00:03:50,940
And over the years,

103

00:03:50,940 --> 00:03:52,490
we have seen that

104

00:03:52,490 --> 00:03:54,040
whatever we can predict

105

00:03:54,040 --> 00:03:56,300
from the theory of quantum mechanics,

106
00:03:56,300 --> 00:03:58,770
most of the experiments that we do today,

107
00:03:58,770 --> 00:04:01,360
the results of those experiments can be

108
00:04:01,360 --> 00:04:04,140
explained using the theory
of quantum mechanics.

109
00:04:04,140 --> 00:04:06,800
So that's the thing that the
world is fundamentally quantum

110
00:04:06,800 --> 00:04:09,140
because almost all the experiments

111
00:04:09,140 --> 00:04:10,300
at the microscopic level,

112
00:04:10,300 --> 00:04:12,430
or at atomic level basically,

113
00:04:12,430 --> 00:04:13,914
can be explained using the,

114
00:04:13,914 --> 00:04:15,900
using the theory of quantum mechanics.

115
00:04:15,900 --> 00:04:18,720
Although the formulation
of quantum mechanics is,

116
00:04:18,720 --> 00:04:20,920
is quite non-intuitive.

117
00:04:20,920 --> 00:04:22,940
- So I have a question there.

– Yeah.

118

00:04:22,940 --> 00:04:25,000

– So as you started to allude to,

119

00:04:25,000 --> 00:04:28,730

there's so many research
fields that people work in now

120

00:04:28,730 --> 00:04:31,940

that are studying different
quantum properties of matter.

121

00:04:31,940 --> 00:04:35,560

So you mentioned quantum
information, quantum computing,

122

00:04:35,560 --> 00:04:38,210

there's also quantum
matter, quantum foundations,

123

00:04:38,210 --> 00:04:39,170

quantum field theory.

124

00:04:39,170 --> 00:04:41,070

There's probably a lot of other fields

125

00:04:41,070 --> 00:04:42,877

that have the word quantum in them.

126

00:04:42,877 --> 00:04:44,800

So can you just tell us a little bit

127

00:04:44,800 --> 00:04:46,300

about that word "quantum"

128

00:04:46,300 --> 00:04:49,320

and really what are some
of those quantum features

129

00:04:49,320 --> 00:04:50,530
that are so interesting

130

00:04:50,530 --> 00:04:52,860
and confusing as opposed to

131

00:04:52,860 --> 00:04:55,577
the features we might be more
used to in classical matter?

132

00:04:55,577 --> 00:04:56,410
- Yeah.

133

00:04:56,410 --> 00:04:58,710
So two of the most intriguing features

134

00:04:58,710 --> 00:05:00,920
are the principle of superposition

135

00:05:00,920 --> 00:05:03,566
and the principle of
entanglement actually,

136

00:05:03,566 --> 00:05:06,530
Schrodinger's cat is a famous example.

137

00:05:06,530 --> 00:05:08,110
Unless until you look at it,

138

00:05:08,110 --> 00:05:11,305
you don't know whether
the cat is dead or alive.

139

00:05:11,305 --> 00:05:12,138
So.

140

00:05:12,138 --> 00:05:12,971

- I'm, this is,

141

00:05:12,971 --> 00:05:15,743
this is the famous thought
experiment with the cat in a box.

142

00:05:15,743 --> 00:05:16,576
And it's a,

143

00:05:16,576 --> 00:05:18,320
it's a sort of metaphor for things

144

00:05:18,320 --> 00:05:20,596
that can be in one state
or another at the same time

145

00:05:20,596 --> 00:05:22,450
until they're measured.

146

00:05:22,450 --> 00:05:23,830
So you don't know if this cat.

147

00:05:23,830 --> 00:05:24,663
- Yeah.

148

00:05:24,663 --> 00:05:25,690
- I, when I was younger,

149

00:05:25,690 --> 00:05:26,950
I thought that was a real cat

150

00:05:26,950 --> 00:05:28,460
in a real box and a real experiment.

151

00:05:28,460 --> 00:05:29,801
I'm glad to know it's not.

152

00:05:29,801 --> 00:05:30,780

(laughs)

153

00:05:30,780 --> 00:05:33,260
So that explains superposition,

154

00:05:33,260 --> 00:05:35,470
this idea of things in the quantum world

155

00:05:35,470 --> 00:05:38,993
being in a state that's
more than one thing.

156

00:05:38,993 --> 00:05:39,826
- Yes.
- At the same time.

157

00:05:39,826 --> 00:05:41,607
- Yeah, that's right.

158

00:05:41,607 --> 00:05:44,373
So for example, if you
take a quantum coin,

159

00:05:44,373 --> 00:05:47,370
a classical coin is either
in the state of heads,

160

00:05:47,370 --> 00:05:50,420
like if you flip it, it
is either heads or tails,

161

00:05:50,420 --> 00:05:53,890
but quantum coin can be
in a superposed state of

162

00:05:53,890 --> 00:05:55,320
heads and tails,

163

00:05:55,320 --> 00:05:57,240

and then you measure it

164

00:05:57,240 --> 00:05:59,700

and you will get either heads or tails

165

00:05:59,700 --> 00:06:02,050

out of your measurement result.

166

00:06:02,050 --> 00:06:04,140

By measuring it again and again,

167

00:06:04,140 --> 00:06:05,840

you will find probabilities

168

00:06:05,840 --> 00:06:08,240

of getting heads as well as tail

169

00:06:08,240 --> 00:06:11,900

and using that, you can

construct the quantum state.

170

00:06:11,900 --> 00:06:16,240

So the quantum coin is basically
in a superposition state.

171

00:06:16,240 --> 00:06:19,810

It is not just only in heads

172

00:06:19,810 --> 00:06:20,980

or in tails.

173

00:06:20,980 --> 00:06:23,750

Like quantum mechanics
isn't a simple theory.

174

00:06:23,750 --> 00:06:24,583

It's not,

175

00:06:24,583 --> 00:06:27,640
it doesn't describe one single instance

176
00:06:27,640 --> 00:06:29,510
of a particle or something.

177
00:06:29,510 --> 00:06:30,890
Like it describes,

178
00:06:30,890 --> 00:06:32,910
like if you do something

179
00:06:32,910 --> 00:06:35,060
over and over many times,

180
00:06:35,060 --> 00:06:37,680
what will be the output that you'll get,

181
00:06:37,680 --> 00:06:39,840
like what will be the
probability of getting.

182
00:06:39,840 --> 00:06:40,940
– It works more in likelihood

183
00:06:40,940 --> 00:06:43,230
and probability than an exact prediction.

184
00:06:43,230 --> 00:06:44,610
– Yeah, that's right.

185
00:06:44,610 --> 00:06:46,720
So if you just measure it once

186
00:06:46,720 --> 00:06:49,040
and see whether it is tail, heads,

187
00:06:49,040 --> 00:06:50,620

you can't really say that it,

188

00:06:50,620 --> 00:06:52,617

whether it is in the
superposition state of heads

189

00:06:52,617 --> 00:06:55,750

plus tail, or whether it is really heads,

190

00:06:55,750 --> 00:06:57,380

you will have to perform

191

00:06:57,380 --> 00:07:00,480

the measurement on the same copy,

192

00:07:00,480 --> 00:07:02,980

on the multiple copies
of the same quantum state

193

00:07:02,980 --> 00:07:05,020

again and again to figure out whether

194

00:07:05,020 --> 00:07:08,060

it is in a superposition state or not.

195

00:07:08,060 --> 00:07:10,490

- This is part of what
confuses a lot of people

196

00:07:10,490 --> 00:07:11,810

about quantum mechanics, right?

197

00:07:11,810 --> 00:07:13,840

This is 'cause we don't experience that.

198

00:07:13,840 --> 00:07:16,218

When we flip a coin, it's
always heads or tails.

199

00:07:16,218 --> 00:07:17,051

- Yeah, that's right.

200

00:07:17,051 --> 00:07:19,310

- Cause it's a, it's a macro world coin.

201

00:07:19,310 --> 00:07:23,600

So it's okay that people
are confused by this, right?

202

00:07:23,600 --> 00:07:24,960

It's not something we experience.

203

00:07:24,960 --> 00:07:25,793

- Yeah.

204

00:07:25,793 --> 00:07:26,990

It is very non-intuitive,

205

00:07:26,990 --> 00:07:29,853

like we don't really observe anything

206

00:07:29,853 --> 00:07:31,340

in a superposition state.

207

00:07:31,340 --> 00:07:33,940

So that's where quantum
foundations come in.

208

00:07:33,940 --> 00:07:35,850

We describe

209

00:07:35,850 --> 00:07:37,040

a quantum particle

210

00:07:37,040 --> 00:07:38,780

using a wave function,

211
00:07:38,780 --> 00:07:41,230
which can be in a superposition state,

212
00:07:41,230 --> 00:07:43,960
but we don't really
observe that wave function.

213
00:07:43,960 --> 00:07:45,790
What we observe is

214
00:07:45,790 --> 00:07:48,730
probabilities of certain
kinds of observables,

215
00:07:48,730 --> 00:07:51,343
like any real observable,
for example, for,

216
00:07:51,343 --> 00:07:52,633
with this coin,

217
00:07:52,633 --> 00:07:54,800
when you measure it in the basis of head,

218
00:07:54,800 --> 00:07:56,260
head and tail, when you measure it,

219
00:07:56,260 --> 00:07:59,280
whether you'll get head
or a tail, actually.

220
00:07:59,280 --> 00:08:01,550
So quantum foundation is like

221
00:08:01,550 --> 00:08:04,060
trying to understand what is real

222
00:08:04,060 --> 00:08:07,450

versus what we infer out of measurement.

223

00:08:07,450 --> 00:08:12,250

So this whole (mumbles)
mathematical formalism

224

00:08:12,250 --> 00:08:13,110

of wave function

225

00:08:13,110 --> 00:08:15,300

is a mathematical construct

226

00:08:15,300 --> 00:08:18,990

because we can't see the wave
function (mumbles), right.

227

00:08:18,990 --> 00:08:22,600

That the quantum particle
is indeed in that state.

228

00:08:22,600 --> 00:08:25,560

We can only infer observables,

229

00:08:25,560 --> 00:08:28,049

measurements of observables actually.

230

00:08:28,049 --> 00:08:28,882

- Right.

231

00:08:28,882 --> 00:08:30,770

- So quantum foundations deals with

232

00:08:30,770 --> 00:08:33,548

trying to understand what is real

233

00:08:33,548 --> 00:08:36,260

versus what we can observe.

234

00:08:36,260 --> 00:08:38,700
Like what is the connection
between those two.

235
00:08:38,700 --> 00:08:41,120
- And I just wanna go
back to something you,

236
00:08:41,120 --> 00:08:43,030
a word that you said a few sentences back,

237
00:08:43,030 --> 00:08:44,200
you were talking about

238
00:08:45,060 --> 00:08:47,650
trying to measure these quantum states.

239
00:08:47,650 --> 00:08:48,990
And you've talked about doing that

240
00:08:48,990 --> 00:08:50,630
on many copies of the same state,

241
00:08:50,630 --> 00:08:51,950
but I think that word copy

242
00:08:51,950 --> 00:08:53,550
is maybe something we should talk about

243
00:08:53,550 --> 00:08:57,250
because I think there's
another interesting property

244
00:08:57,250 --> 00:08:58,150
in quantum mechanics,

245
00:08:58,150 --> 00:08:59,540
but you can't actually

246

00:08:59,540 --> 00:09:00,914
make an exact copy of a state.

247

00:09:00,914 --> 00:09:02,230
Is that right?

248

00:09:02,230 --> 00:09:03,063
- You can,

249

00:09:03,063 --> 00:09:07,000
you can't make an exact copy
of an unknown quantum state.

250

00:09:07,000 --> 00:09:09,460
So that's no cloning theorem actually.

251

00:09:09,460 --> 00:09:13,323
Like once you know what is the
quantum state mathematically,

252

00:09:13,323 --> 00:09:15,647
you can prepare many copies of it.

253

00:09:15,647 --> 00:09:17,760
But if you don't know

254

00:09:17,760 --> 00:09:19,410
what is the quantum state of a particle,

255

00:09:19,410 --> 00:09:20,243
you can't copy it.

256

00:09:20,243 --> 00:09:23,180
And that is a principle that is,

257

00:09:23,180 --> 00:09:26,460
that would be used in many
different types of applications

258

00:09:26,460 --> 00:09:27,450
of quantum information

259

00:09:27,450 --> 00:09:28,870
and quantum computing,

260

00:09:28,870 --> 00:09:31,120
actually like quantum cryptography.

261

00:09:31,120 --> 00:09:33,910
– And that's different than
in classical cryptography.

262

00:09:33,910 --> 00:09:34,880
Is that right?

263

00:09:34,880 --> 00:09:35,713
– Yeah.

264

00:09:35,713 --> 00:09:37,830
Like you can create copies
of something basically

265

00:09:37,830 --> 00:09:40,240
in quantum, classical cryptography

266

00:09:40,240 --> 00:09:43,100
without other people
knowing about it actually.

267

00:09:43,100 --> 00:09:44,670
But quantum state,

268

00:09:44,670 --> 00:09:46,650
like as soon as you measure,

269

00:09:46,650 --> 00:09:49,480

the quantum state of particle
is destroyed actually.

270

00:09:49,480 --> 00:09:53,350

So once it is destroyed, the other,

271

00:09:53,350 --> 00:09:55,449

the receiver end will know

272

00:09:55,449 --> 00:09:56,290

that

273

00:09:57,270 --> 00:09:59,881

it has been intercepted by,

274

00:09:59,881 --> 00:10:02,330

by some Eve actually.

275

00:10:02,330 --> 00:10:04,160

- Is that the quantum cryptography

276

00:10:04,160 --> 00:10:05,870

or the idea of quantum encryption

277

00:10:05,870 --> 00:10:08,080

that measuring a quantum state changes it

278

00:10:08,080 --> 00:10:11,790

and therefore you can detect
whether it's been measured?

279

00:10:11,790 --> 00:10:13,483

- Yeah, that's right.

280

00:10:13,483 --> 00:10:14,870

- So, and that's a,

281

00:10:14,870 --> 00:10:17,010

that's sort of a branch
of quantum computing

282
00:10:17,010 --> 00:10:18,010
and quantum information.

283
00:10:18,010 --> 00:10:19,340
I wanted to get back to that

284
00:10:19,340 --> 00:10:21,640
'cause you said you work
at these intersections

285
00:10:21,640 --> 00:10:22,790
of quantum information,

286
00:10:22,790 --> 00:10:24,960
which is related to quantum computers,

287
00:10:24,960 --> 00:10:26,180
which are in theory,

288
00:10:26,180 --> 00:10:30,696
these very powerful computers
that harness superposition.

289
00:10:30,696 --> 00:10:31,940
And, but you said you're
at the intersections

290
00:10:31,940 --> 00:10:34,210
of quantum computing
and quantum foundations.

291
00:10:34,210 --> 00:10:38,480
So which questions are currently sort of

292
00:10:38,480 --> 00:10:39,780
the focus of your attention?

293

00:10:39,780 --> 00:10:41,490

What are you trying to figure out?

294

00:10:41,490 --> 00:10:43,563

- I became interested in,

295

00:10:44,740 --> 00:10:46,040

in chaos actually.

296

00:10:46,040 --> 00:10:49,920

So initially I did a few projects in my,

297

00:10:49,920 --> 00:10:52,140

during my undergrad studies

298

00:10:52,140 --> 00:10:54,540

in the field of classical chaos.

299

00:10:54,540 --> 00:10:56,970

And then I did a project

300

00:10:56,970 --> 00:10:58,323

in the field of quantum chaos.

301

00:10:58,323 --> 00:10:59,904

- So can you actually just start

302

00:10:59,904 --> 00:11:03,610

by telling us what classical
chaos is maybe before we,

303

00:11:03,610 --> 00:11:05,180

I know that's not really what you work in,

304

00:11:05,180 --> 00:11:06,740

but it might be useful to start there.

305

00:11:06,740 --> 00:11:09,520

- Chaos is a pretty loaded
term, non scientifically,

306

00:11:09,520 --> 00:11:12,470

but chaos is a very
specific meaning in your.

307

00:11:12,470 --> 00:11:14,340

- Many people would be familiar

308

00:11:14,340 --> 00:11:16,760

with the term butterfly effect.

309

00:11:16,760 --> 00:11:19,320

So it is like if,

310

00:11:19,320 --> 00:11:21,110

can the flap of a,

311

00:11:21,110 --> 00:11:22,870

of the wings of a butterfly

312

00:11:22,870 --> 00:11:27,180

in Brazil cause a tornado say in Germany.

313

00:11:27,180 --> 00:11:28,540

So that's the butterfly effect,

314

00:11:28,540 --> 00:11:30,532

can very small changes
in the initial conditions

315

00:11:30,532 --> 00:11:35,330

lead to vast differences in the outcome.

316

00:11:35,330 --> 00:11:38,940

Chaos is basically unpredictability due to

317

00:11:38,940 --> 00:11:41,300
sensitivity to initial conditions.

318

00:11:41,300 --> 00:11:43,920
Like the seeds of chaos theory

319

00:11:43,920 --> 00:11:45,990
were sewn by Henri Poincare,

320

00:11:45,990 --> 00:11:47,920
but then it was well formulated

321

00:11:47,920 --> 00:11:52,480
by a meteorologist, Edward
Lorentz, around 1960s,

322

00:11:52,480 --> 00:11:55,530
had built a weather model and.

323

00:11:55,530 --> 00:11:58,210
- Sorry, a meteorologist
came up with chaos theory?

324

00:11:58,210 --> 00:11:59,043
- Yeah.
- Okay.

325

00:11:59,043 --> 00:12:00,170
I didn't know.

326

00:12:00,170 --> 00:12:02,950
Is weather and meteorology is that,

327

00:12:02,950 --> 00:12:04,740
that's classical chaos theory,

328

00:12:04,740 --> 00:12:06,240

that has nothing to do with quantum.

329

00:12:06,240 --> 00:12:07,910

- Chaos is basically a property

330

00:12:07,910 --> 00:12:11,010

of classical dynamical
systems, not just physics,

331

00:12:11,010 --> 00:12:13,650

like any kind of dynamical
systems you want to predict.

332

00:12:13,650 --> 00:12:14,690

Like for example,

333

00:12:14,690 --> 00:12:16,393

the population of fish in a pond

334

00:12:17,959 --> 00:12:20,237

or weather is another example.

335

00:12:20,237 --> 00:12:22,450

And then even in stock market
or something like that,

336

00:12:22,450 --> 00:12:25,840

chaos has applications in every,

337

00:12:25,840 --> 00:12:26,980

so many fields actually.

338

00:12:26,980 --> 00:12:28,550

So dynamical system is basically

339

00:12:28,550 --> 00:12:30,410

any system that evolves with time.

340

00:12:30,410 --> 00:12:31,437
- Sorry, you said a,

341
00:12:31,437 --> 00:12:32,674
a dynamical system.
- Dynamical system.

342
00:12:32,674 --> 00:12:35,800
It's any system that evolves with time.

343
00:12:35,800 --> 00:12:39,230
And so you basically have
either differential equations,

344
00:12:39,230 --> 00:12:42,220
like you have a set of
variables, for example,

345
00:12:42,220 --> 00:12:45,100
for whether you can have
variables as temperature,

346
00:12:45,100 --> 00:12:46,930
pressure or something like that.

347
00:12:46,930 --> 00:12:49,180
And differential equations

348
00:12:49,180 --> 00:12:53,030
telling us how those
evolve with time basically.

349
00:12:53,030 --> 00:12:55,070
So now these differential equations,

350
00:12:55,070 --> 00:12:57,210
if they are nonlinear,

351
00:12:57,210 --> 00:13:00,600

if they nonlinearly depend
on the other variables,

352

00:13:00,600 --> 00:13:03,370
then it results in.

353

00:13:03,370 --> 00:13:05,210
- Maybe I'll, I'll just ask a question

354

00:13:05,210 --> 00:13:06,710
to make sure I'm understanding.

355

00:13:06,710 --> 00:13:08,870
You're saying that, you know,
weather can be an example.

356

00:13:08,870 --> 00:13:12,410
So is this why I might
sometimes look at my phone

357

00:13:12,410 --> 00:13:14,060
and see that it's
supposed to rain tomorrow,

358

00:13:14,060 --> 00:13:15,380
but then it doesn't actually rain.

359

00:13:15,380 --> 00:13:17,500
Is that, is that because

360

00:13:17,500 --> 00:13:18,830
it's very difficult to predict,

361

00:13:18,830 --> 00:13:20,750
is that related to the fact
that it's a chaotic system?

362

00:13:20,750 --> 00:13:23,440
- The weather is a chaotic system.

363

00:13:23,440 --> 00:13:24,460

That's right.

364

00:13:24,460 --> 00:13:25,950

So the thing is like,

365

00:13:25,950 --> 00:13:29,180

we all know that we can't
really predict the weather

366

00:13:29,180 --> 00:13:30,013

of any place.

367

00:13:30,013 --> 00:13:30,846

Like for example,

368

00:13:30,846 --> 00:13:33,410

if we look at the weather
of Waterloo today,

369

00:13:33,410 --> 00:13:36,920

how is it going to be
tomorrow or day after?

370

00:13:36,920 --> 00:13:39,330

And we see that many times,

371

00:13:39,330 --> 00:13:43,070

it's not the same as what
it is tomorrow, right?

372

00:13:43,070 --> 00:13:44,500

So why is that the case?

373

00:13:44,500 --> 00:13:47,363

We have advanced technologically so much,

374

00:13:48,270 --> 00:13:51,610
but still we can't really
predict the weather

375
00:13:51,610 --> 00:13:54,370
a few days in advance of any place.

376
00:13:54,370 --> 00:13:55,520
If we had predicted,

377
00:13:55,520 --> 00:13:59,800
like if we could have
predicted so many catastrophes

378
00:13:59,800 --> 00:14:02,470
and on earth would have been,

379
00:14:02,470 --> 00:14:04,260
could have been like avoided,

380
00:14:04,260 --> 00:14:05,093
or not avoided,

381
00:14:05,093 --> 00:14:06,120
the destruction could have been avoided.

382
00:14:06,120 --> 00:14:07,840
- Yeah, if you knew a hurricane was coming

383
00:14:07,840 --> 00:14:09,813
a month in advance,
rather than a few days.

384
00:14:09,813 --> 00:14:10,646
- Yeah.
- In advance,

385
00:14:10,646 --> 00:14:11,479
you'd be.

- Something like that.

386

00:14:11,479 --> 00:14:12,799

- You'd be grateful for chaos theory.

387

00:14:12,799 --> 00:14:14,217

(laughs)

388

00:14:14,217 --> 00:14:15,510

- But the thing is

389

00:14:15,510 --> 00:14:18,180

they are predicted only

a few days in advance

390

00:14:18,180 --> 00:14:20,800

with some probability

that this could happen.

391

00:14:20,800 --> 00:14:24,760

So it is because like

these models are nonlinear,

392

00:14:24,760 --> 00:14:27,610

so they can't be solved exactly.

393

00:14:27,610 --> 00:14:29,840

And they can exhibit chaos that

394

00:14:29,840 --> 00:14:32,020

whatever initial condition we input,

395

00:14:32,020 --> 00:14:33,890

for example, the temperature or pressure,

396

00:14:33,890 --> 00:14:35,810

whatever we input in,

397

00:14:35,810 --> 00:14:36,760
in the bunch of,

398
00:14:36,760 --> 00:14:40,620
for the variables in the bunch
of differential equations,

399
00:14:40,620 --> 00:14:44,930
those variables will have
some error in the last visit.

400
00:14:44,930 --> 00:14:47,260
Like if we have five visit (mumbles)

401
00:14:47,260 --> 00:14:49,930
in our value of the temperature,

402
00:14:49,930 --> 00:14:53,260
there is a small error in the fifth visit

403
00:14:53,260 --> 00:14:54,800
after the decimal, right?

404
00:14:54,800 --> 00:14:57,210
So that very small error

405
00:14:57,210 --> 00:14:58,630
in the last visit

406
00:14:58,630 --> 00:15:01,160
actually can amplify

407
00:15:01,160 --> 00:15:02,875
upon evolution of the system.

408
00:15:02,875 --> 00:15:03,750
– Right.

409

00:15:03,750 --> 00:15:07,710

- The more precise we
are in the initial value.

410

00:15:07,710 --> 00:15:09,540

- String of digits after the decimal.

411

00:15:09,540 --> 00:15:10,800

- Yeah.

- Is.

412

00:15:10,800 --> 00:15:13,460

- The longer we can
actually predict the weather

413

00:15:13,460 --> 00:15:18,150

to the likelihood of
the weather in advance,

414

00:15:18,150 --> 00:15:21,880

but it will lead to
unpredictability after some time,

415

00:15:21,880 --> 00:15:24,460

no matter how much precision you're given,

416

00:15:24,460 --> 00:15:27,440

there is going to be some error in the end

417

00:15:27,440 --> 00:15:31,360

and that will lead to
unpredictability in the long term.

418

00:15:31,360 --> 00:15:34,363

So that's why weather is
an unpredictable system.

419

00:15:34,363 --> 00:15:35,480

But that's the thing.

420

00:15:35,480 --> 00:15:37,810
Weather is a very complex model

421

00:15:37,810 --> 00:15:39,710
and it may look like chaos is a property

422

00:15:39,710 --> 00:15:41,530
of very complex models,

423

00:15:41,530 --> 00:15:43,090
but that's not true.

424

00:15:43,090 --> 00:15:44,670
Even very, very simple systems,

425

00:15:44,670 --> 00:15:47,140
for example, double pendulum, is chaotic.

426

00:15:47,140 --> 00:15:48,770
So double pendulum is basically like

427

00:15:48,770 --> 00:15:50,270
you have some simple pendulum

428

00:15:50,270 --> 00:15:51,710
in which you have a bob

429

00:15:51,710 --> 00:15:54,484
attached to like some knob,

430

00:15:54,484 --> 00:15:58,860
which oscillates in a plane.

431

00:15:58,860 --> 00:16:02,750
Now you attach one more bob
to the end of the first bob.

432

00:16:02,750 --> 00:16:04,220
- So I have kind of a,

433
00:16:04,220 --> 00:16:07,170
a stick or something
with a ball on the end.

434
00:16:07,170 --> 00:16:08,591
And then I have another.
- Yeah.

435
00:16:08,591 --> 00:16:11,210
- Rod attached to that with
another ball on the end.

436
00:16:11,210 --> 00:16:12,230
- Yeah.
- And it can swing

437
00:16:12,230 --> 00:16:13,820
independently of the first, right?

438
00:16:13,820 --> 00:16:16,030
The first ball can swing,

439
00:16:16,030 --> 00:16:19,430
would not independently but affected by.

440
00:16:19,430 --> 00:16:21,320
- They will be dependent in some way,

441
00:16:21,320 --> 00:16:24,780
but overall the motion is chaotic actually

442
00:16:24,780 --> 00:16:28,670
like you can search various
YouTube videos actually that.

443
00:16:28,670 --> 00:16:30,440

- They're really fun to watch
by the way, double pendulums.

444

00:16:30,440 --> 00:16:31,370
- Yeah.

445

00:16:31,370 --> 00:16:32,690
- Good hypnotic entertainment.

446

00:16:32,690 --> 00:16:35,780
- Very small initial condition change

447

00:16:35,780 --> 00:16:38,891
can lead to high
unpredictability actually.

448

00:16:38,891 --> 00:16:40,340
So that's the thing,

449

00:16:40,340 --> 00:16:43,190
that chaos is not just a
property of complex systems,

450

00:16:43,190 --> 00:16:46,064
but very, very simple
systems can exhibit chaos.

451

00:16:46,064 --> 00:16:46,897
- Interesting.
- So I,

452

00:16:46,897 --> 00:16:48,910
I wanna ask something here
just to make sure I understand.

453

00:16:48,910 --> 00:16:50,720
So you're saying with weather,

454

00:16:50,720 --> 00:16:53,111

if I'm say measuring the temperature,

455

00:16:53,111 --> 00:16:55,830

it might be, say 20 degrees Celsius,

456

00:16:55,830 --> 00:16:58,050

but I'm not sure if it's 20 degrees

457

00:16:58,050 --> 00:17:01,600

or 20.0001 degree Celsius.

458

00:17:01,600 --> 00:17:03,220

This seems like a very small change.

459

00:17:03,220 --> 00:17:06,650

And if it was a non chaotic system,

460

00:17:06,650 --> 00:17:08,300

maybe the result two days later

461

00:17:08,300 --> 00:17:11,370

wouldn't depend so much on

whether it was 20 degrees Celsius

462

00:17:11,370 --> 00:17:13,030

or 20.0001.

463

00:17:13,030 --> 00:17:15,190

But because it's such a complicated system

464

00:17:15,190 --> 00:17:16,920

that's non-linear

465

00:17:16,920 --> 00:17:18,930

and we call it chaotic,

466

00:17:18,930 --> 00:17:22,050

it's in the end gonna depend a lot

467

00:17:22,050 --> 00:17:24,510
on that really small
difference in that variable.

468

00:17:24,510 --> 00:17:25,600
Is that correct?

469

00:17:25,600 --> 00:17:26,450
- Yeah, that's right.

470

00:17:26,450 --> 00:17:30,010
So that small difference
in nonlinear systems

471

00:17:30,010 --> 00:17:33,620
put in principle amplify
to very large differences

472

00:17:33,620 --> 00:17:35,950
in an unpredictable manner.

473

00:17:35,950 --> 00:17:37,680
But if it is a linear system

474

00:17:37,680 --> 00:17:39,544
or if it is an integrable
or regular system,

475

00:17:39,544 --> 00:17:42,280
like different words for the same time,

476

00:17:42,280 --> 00:17:47,280
then those small differences
won't amplify a lot actually,

477

00:17:47,900 --> 00:17:50,367
or it'll amplify a very
predictable manner.

478

00:17:50,367 --> 00:17:52,545

- I see.

- If it'll amplify,

479

00:17:52,545 --> 00:17:55,710

like there can be unstable
boundary systems in ways,

480

00:17:55,710 --> 00:17:59,670

things can amplify, but we
still know how it amplifies.

481

00:17:59,670 --> 00:18:00,970

So.

- So,

482

00:18:00,970 --> 00:18:02,410

may I jump in?

483

00:18:02,410 --> 00:18:04,850

A quantum system,

484

00:18:04,850 --> 00:18:08,540

is that more complex or
less complex than weather?

485

00:18:08,540 --> 00:18:10,163

Quantum being very small and,

486

00:18:11,053 --> 00:18:11,980

and there's parameters around it.

487

00:18:11,980 --> 00:18:14,680

What does quantum chaos refer to?

488

00:18:14,680 --> 00:18:18,480

- Quantum chaos has not been
very well understood yet.

489

00:18:18,480 --> 00:18:20,550

Although it's been like a hundred years

490

00:18:20,550 --> 00:18:22,810

of the development of quantum theory

491

00:18:22,810 --> 00:18:24,457

and why is quantum chaos

492

00:18:24,457 --> 00:18:26,180

and quantum classical correspondence

493

00:18:26,180 --> 00:18:27,210

is an important problem.

494

00:18:27,210 --> 00:18:28,840

I'll like to give another example.

495

00:18:28,840 --> 00:18:33,840

For example, Galilean
relativity was well known from

496

00:18:34,400 --> 00:18:36,570

a few centuries, right?

497

00:18:36,570 --> 00:18:39,930

And then came in a special
theory of relativity

498

00:18:39,930 --> 00:18:44,190

where the speed of the object
can be very, very high.

499

00:18:44,190 --> 00:18:48,750

Now, as you start reducing
the speed of the object

500

00:18:48,750 --> 00:18:50,463
towards normal speed,

501
00:18:51,360 --> 00:18:53,100
special theory of relativity,

502
00:18:53,100 --> 00:18:56,560
very smoothly merges into
Galilean theory of relativity.

503
00:18:56,560 --> 00:18:58,970
It's not like Galilean theory
of relativity is wrong, right?

504
00:18:58,970 --> 00:19:01,440
It is still right at the level

505
00:19:01,440 --> 00:19:03,860
we observe our everyday world.

506
00:19:03,860 --> 00:19:04,693
Then this new theory of,

507
00:19:04,693 --> 00:19:07,610
this new theory of relativity was formed.

508
00:19:07,610 --> 00:19:08,986
- By Einstein is?

509
00:19:08,986 --> 00:19:09,819
- Yeah.
- Okay.

510
00:19:09,819 --> 00:19:11,393
- That's right.
- I got that one right.

511
00:19:11,393 --> 00:19:12,244
(laughs)

512

00:19:12,244 --> 00:19:16,070

- And then it smoothly
merged with the old theory

513

00:19:16,070 --> 00:19:19,540

where the old theory was
predicting things very well

514

00:19:19,540 --> 00:19:21,958

in normal circumstances,

515

00:19:21,958 --> 00:19:24,160

which we can observe through our eyes.

516

00:19:24,160 --> 00:19:27,330

Likewise, classical physics is very,

517

00:19:27,330 --> 00:19:30,110

can't very well predict our everyday world

518

00:19:30,110 --> 00:19:31,660

that we see around

519

00:19:31,660 --> 00:19:32,810

most of the things.

520

00:19:32,810 --> 00:19:34,470

And then quantum theory

521

00:19:34,470 --> 00:19:36,880

is something that describes phenomena.

522

00:19:36,880 --> 00:19:38,580

The microscopic level

523

00:19:38,580 --> 00:19:41,090

are at levels, which is,

524

00:19:41,090 --> 00:19:42,650
does not happen in normal

525

00:19:42,650 --> 00:19:46,330
or circumstance in for
example, very low temperatures,

526

00:19:46,330 --> 00:19:49,100
chem temperatures near zero
Kelvin or something like that.

527

00:19:49,100 --> 00:19:50,270
We don't really see that.

528

00:19:50,270 --> 00:19:52,850
So for example, super conductivity.

529

00:19:52,850 --> 00:19:55,990
So you can see defective
super conductivity

530

00:19:55,990 --> 00:19:57,170
at a macroscopic level.

531

00:19:57,170 --> 00:19:59,700
It's a big object visible
to our eyes, right.

532

00:19:59,700 --> 00:20:01,719
And we see that, but we can't ex--

533

00:20:01,719 --> 00:20:05,760
- A levitating super magnetic
train or something like that.

534

00:20:05,760 --> 00:20:07,390
- Yeah, that's right.

535
00:20:07,390 --> 00:20:08,950
So,

536
00:20:08,950 --> 00:20:11,660
so that happens at very,
very small temperatures,

537
00:20:11,660 --> 00:20:12,930
although it is macroscopic,

538
00:20:12,930 --> 00:20:14,953
but quantum mechanics is
the thing that predicts it

539
00:20:14,953 --> 00:20:16,020
where a thing is there,

540
00:20:16,020 --> 00:20:20,458
there has to be something
different from normal circumstance

541
00:20:20,458 --> 00:20:22,120
where classical physics fails,

542
00:20:22,120 --> 00:20:24,490
for example, very,

543
00:20:24,490 --> 00:20:27,340
very low temperature or very,

544
00:20:27,340 --> 00:20:29,085
or microscopic scale

545
00:20:29,085 --> 00:20:33,210
in terms of like size of an
object or something like that.

546
00:20:33,210 --> 00:20:37,060

So quantum theory explains
the microscopic world

547

00:20:37,060 --> 00:20:39,054
or the world

548

00:20:39,054 --> 00:20:43,280
or other circumstances where things are

549

00:20:43,280 --> 00:20:45,560
very different from what
we observe in day to day

550

00:20:45,560 --> 00:20:48,200
like temperature or something like that.

551

00:20:48,200 --> 00:20:50,520
And then classical physics
explains our everyday world.

552

00:20:50,520 --> 00:20:52,080
So in principle,

553

00:20:52,080 --> 00:20:54,510
quantum theory should merge

554

00:20:54,510 --> 00:20:56,620
as we scale up the size of the object

555

00:20:56,620 --> 00:20:58,350
or as we'll scale up the temperature

556

00:20:58,350 --> 00:21:00,310
or something like that of the system.

557

00:21:00,310 --> 00:21:02,890
Quantum theory should very smoothly merge

558

00:21:02,890 --> 00:21:03,723
into classical physics.

559
00:21:03,723 --> 00:21:07,240
And we should be able to
understand that convergence

560
00:21:07,240 --> 00:21:08,920
because classical physics is not wrong.

561
00:21:08,920 --> 00:21:10,383
At least, we know that,

562
00:21:10,383 --> 00:21:13,440
know that most of the things
around us is spread is,

563
00:21:13,440 --> 00:21:16,100
could be predicted
using classical physics.

564
00:21:16,100 --> 00:21:18,640
This is the field of quantum
classical correspondence

565
00:21:18,640 --> 00:21:20,440
and it is more or less,

566
00:21:20,440 --> 00:21:24,400
fairly understood for
integrable or regular systems,

567
00:21:24,400 --> 00:21:25,540
but for chaotic systems,

568
00:21:25,540 --> 00:21:28,440
it is not still understood.

569
00:21:28,440 --> 00:21:29,273

- Why is that?

570

00:21:29,273 --> 00:21:32,030

Is it just because it's a
extremely difficult subject

571

00:21:32,030 --> 00:21:33,250

that's difficult to measure,

572

00:21:33,250 --> 00:21:36,220

you're dealing with tiny microscopic--

573

00:21:36,220 --> 00:21:38,150

- So there are fundamental differences

574

00:21:38,150 --> 00:21:41,550

how in the formulation
of quantum mechanics

575

00:21:41,550 --> 00:21:43,620

and classical physics, actually.

576

00:21:43,620 --> 00:21:44,880

In classical physics,

577

00:21:44,880 --> 00:21:48,290

we've see chaos through
trajectories actually

578

00:21:48,290 --> 00:21:49,130

in phase space,

579

00:21:49,130 --> 00:21:51,690

like phase space is something
like you take the position

580

00:21:51,690 --> 00:21:52,930

and momentum of a particle

581

00:21:52,930 --> 00:21:56,430
and then track how the
position and momentum evolves

582

00:21:56,430 --> 00:21:59,820
and it will curve out a
trajectory in the phase space.

583

00:21:59,820 --> 00:22:00,930
– And what's a trajectory?

584

00:22:00,930 --> 00:22:03,060
Just kind of the path that it follows.

585

00:22:03,060 --> 00:22:03,983
– Yeah, that's right.

586

00:22:03,983 --> 00:22:05,050
But not just position,

587

00:22:05,050 --> 00:22:07,950
you have to add, there is
another axis, which is momentum.

588

00:22:07,950 --> 00:22:09,860
So in general, when we see a particle,

589

00:22:09,860 --> 00:22:11,390
it's just position, right.

590

00:22:11,390 --> 00:22:14,430
But there is a momentum
associated to the particle,

591

00:22:14,430 --> 00:22:16,350
which is for normal particles.

592

00:22:16,350 --> 00:22:17,650

It is mass times velocity.

593

00:22:19,130 --> 00:22:21,050

So that is another axis.

594

00:22:21,050 --> 00:22:25,310

So the phase base is formulated
by position plus momentum.

595

00:22:25,310 --> 00:22:27,300

So classically it is possible to measure

596

00:22:27,300 --> 00:22:30,850

the position and momentum
of particles precisely.

597

00:22:30,850 --> 00:22:34,200

And the chaos occurs in
the finest structures

598

00:22:34,200 --> 00:22:35,060

of the phase base

599

00:22:35,060 --> 00:22:37,190

carved through these
trajectories actually.

600

00:22:37,190 --> 00:22:38,980

But quantum mechanically,

601

00:22:38,980 --> 00:22:41,510

due to Heisenberg's uncertainty principle,

602

00:22:41,510 --> 00:22:45,180

we can't have precise values of

603

00:22:45,180 --> 00:22:47,030

position and momentum at the same time.

604

00:22:47,030 --> 00:22:49,940

So we don't have trajectories
in quantum mechanics

605

00:22:49,940 --> 00:22:52,820

just like the way we have
it in classical physics.

606

00:22:52,820 --> 00:22:56,110

So this is one of the fundamental reasons

607

00:22:56,110 --> 00:22:59,730

we can't pick up the definition of

608

00:22:59,730 --> 00:23:01,010

chaos in classical physics

609

00:23:01,010 --> 00:23:04,240

and use it in quantum physics actually.

610

00:23:04,240 --> 00:23:06,060

So just because quantum physics

611

00:23:06,060 --> 00:23:08,190

is formulated in a very different manner

612

00:23:08,190 --> 00:23:09,760

than in classical physics,

613

00:23:09,760 --> 00:23:12,060

understanding chaos in quantum physics,

614

00:23:12,060 --> 00:23:14,510

the same way as it is
done in classical physics

615

00:23:14,510 --> 00:23:15,770

is not possible.

616

00:23:15,770 --> 00:23:17,720

But as I talked about earlier,

617

00:23:17,720 --> 00:23:19,130

there should be a smooth convergence

618

00:23:19,130 --> 00:23:20,790

of quantum physics into classical physics

619

00:23:20,790 --> 00:23:22,936

as we scale up the,

620

00:23:22,936 --> 00:23:25,180

the size of the object

or things like that.

621

00:23:25,180 --> 00:23:26,810

And in quantum mechanics,

622

00:23:26,810 --> 00:23:28,970

the superposition and entanglement

623

00:23:28,970 --> 00:23:31,380

are two purely quantum properties,

624

00:23:31,380 --> 00:23:33,410

not there in the classical world.

625

00:23:33,410 --> 00:23:35,930

And entanglement is like,

626

00:23:35,930 --> 00:23:37,990

if you have a,

627

00:23:37,990 --> 00:23:39,990

we were talking about quantum coins.

628
00:23:39,990 --> 00:23:42,710
So if you have a couple of quantum coins,

629
00:23:42,710 --> 00:23:44,530
if the coin is classical, you both,

630
00:23:44,530 --> 00:23:46,521
if both can be in heads
or both can be in tails,

631
00:23:46,521 --> 00:23:49,460
or one can be head and one can be tail.

632
00:23:49,460 --> 00:23:50,830
But quantum mechanically,

633
00:23:50,830 --> 00:23:54,370
you can have a state
like a superposition of

634
00:23:54,370 --> 00:23:56,460
head, head, plus tail tail,

635
00:23:56,460 --> 00:23:57,780
something like that.

636
00:23:57,780 --> 00:24:00,830
And when you measure one of the coin,

637
00:24:00,830 --> 00:24:03,440
if the pair of quantum coin

638
00:24:03,440 --> 00:24:05,690
is in this state that I talked about,

639
00:24:05,690 --> 00:24:07,190
head head plus tail tail,

640

00:24:07,190 --> 00:24:10,210
then if you measure one coin

641

00:24:10,210 --> 00:24:12,140
and if it comes out to be heads,

642

00:24:12,140 --> 00:24:15,830
the other coin is bound to give heads

643

00:24:15,830 --> 00:24:17,180
when you measure it.

644

00:24:17,180 --> 00:24:19,480
Likewise, if the first
coin comes out to be tail,

645

00:24:19,480 --> 00:24:22,307
when you measure it, the other
coin is bound to be in tail.

646

00:24:22,307 --> 00:24:24,280
- And this is even if the two coins

647

00:24:24,280 --> 00:24:26,630
are far away from each other.

648

00:24:26,630 --> 00:24:27,900
- Yeah, this.
- Held by,

649

00:24:27,900 --> 00:24:29,030
handled by separate people.

650

00:24:29,030 --> 00:24:32,121
Is this, this is what Einstein
said was spooky action.

651

00:24:32,121 --> 00:24:32,954

- Yeah, that's right.

652

00:24:32,954 --> 00:24:34,420

- Where it's where it seems
like one thing far away

653

00:24:34,420 --> 00:24:37,290

is happening at the very same time is as,

654

00:24:37,290 --> 00:24:38,640

as a different thing.

655

00:24:38,640 --> 00:24:39,910

I know that's

656

00:24:39,910 --> 00:24:42,360

probably not the scientific explanation,

657

00:24:42,360 --> 00:24:44,580

but that's, is it fair to say that

658

00:24:45,450 --> 00:24:48,360

that's one of the things
that we just don't experience

659

00:24:48,360 --> 00:24:49,700

in our everyday lives?

660

00:24:49,700 --> 00:24:51,080

- Yeah, that's right.

- So we have a hard time

661

00:24:51,080 --> 00:24:52,400

wrapping our heads around it?

662

00:24:52,400 --> 00:24:53,233

- Yeah, that's right.

663

00:24:53,233 --> 00:24:54,439

So that's the thing

664

00:24:54,439 --> 00:24:56,150

that if you prepare
these two quantum coins

665

00:24:56,150 --> 00:24:59,190

and suppose you give one of them to Alice,

666

00:24:59,190 --> 00:25:00,590

other of them to Bob,

667

00:25:00,590 --> 00:25:01,750

and if they are prepared

668

00:25:01,750 --> 00:25:03,180

in this joint quantum state,

669

00:25:03,180 --> 00:25:05,950

entangled quantum state
and Alice suppose goes,

670

00:25:05,950 --> 00:25:08,470

goes to Australia and
Bob lives here in Canada,

671

00:25:08,470 --> 00:25:12,020

and then Bob measures his quantum coin.

672

00:25:12,020 --> 00:25:14,440

And if he gets heads

673

00:25:14,440 --> 00:25:17,700

and then instantly Alice will observe

674

00:25:17,700 --> 00:25:19,980

if she makes a measurement
on it, on her coin,

675

00:25:19,980 --> 00:25:23,250
that it is in head actually.

676

00:25:23,250 --> 00:25:24,771
Likewise, if Bob gets tails,

677

00:25:24,771 --> 00:25:27,660
then Alice will see to be tail.

678

00:25:27,660 --> 00:25:28,970
So that's the thing like.

679

00:25:28,970 --> 00:25:30,183
- That is spooky.

680

00:25:30,183 --> 00:25:32,192
- That is spooky.

681

00:25:32,192 --> 00:25:35,120
And that's the thing that we have observe.

682

00:25:35,120 --> 00:25:37,270
This is called non-local correlation

683

00:25:37,270 --> 00:25:40,780
because it's not like
a measurement in Canada

684

00:25:40,780 --> 00:25:44,950
is affecting something in
Australia and instantly.

685

00:25:44,950 --> 00:25:46,870
So, and we know that information

686

00:25:46,870 --> 00:25:50,100
can at most travel with

the speed of light.

687

00:25:50,100 --> 00:25:51,650

It can't travel beyond that.

688

00:25:51,650 --> 00:25:52,950

So how does this happen?

689

00:25:52,950 --> 00:25:55,780

So that's why it is called
non-local correlation.

690

00:25:55,780 --> 00:25:57,050

The thing is like,

691

00:25:57,050 --> 00:26:01,010

this is very surprising that this happens,

692

00:26:01,010 --> 00:26:05,620

but it is found to be true in
several experiments, actually.

693

00:26:05,620 --> 00:26:08,150

So, and it is still a question

694

00:26:08,150 --> 00:26:09,300

like, how does this happen?

695

00:26:09,300 --> 00:26:12,390

How do we understand
actually, that this happens.

696

00:26:12,390 --> 00:26:14,780

It is very, very surprising in that way.

697

00:26:14,780 --> 00:26:16,440

– It seems like there are

698

00:26:16,440 --> 00:26:19,890
a number of mysteries
that need to be solved.

699
00:26:19,890 --> 00:26:21,840
And you've mentioned sort of the big,

700
00:26:21,840 --> 00:26:23,510
a big one of,

701
00:26:23,510 --> 00:26:26,590
at what point does the quantum world

702
00:26:26,590 --> 00:26:30,520
sort of move into the
classical world that we inhabit

703
00:26:30,520 --> 00:26:35,003
and why is it so hard to
sort of pin that down that,

704
00:26:35,867 --> 00:26:37,605
that making general relativity

705
00:26:37,605 --> 00:26:41,060
and quantum mechanics
play nicely together?

706
00:26:41,060 --> 00:26:43,387
Because that seems to be
the focus of a lot of work

707
00:26:43,387 --> 00:26:45,640
is understanding the,

708
00:26:45,640 --> 00:26:48,726
the change between quantum and classical.

709
00:26:48,726 --> 00:26:50,100

– So these are two different questions actually.

710

00:26:50,100 --> 00:26:52,420

– Okay, well then, yeah,
I can rephrase that.

711

00:26:52,420 --> 00:26:54,700

I guess I'm getting at this question of

712

00:26:54,700 --> 00:26:57,550

understanding where quantum ends

713

00:26:57,550 --> 00:26:59,080

and where classical begins and,

714

00:26:59,080 --> 00:27:02,633

and why there's not sort
of a total agreement there.

715

00:27:03,720 --> 00:27:06,528

Why is it so challenging to find this,

716

00:27:06,528 --> 00:27:08,950

I guess unified theory?

717

00:27:08,950 --> 00:27:12,530

– Quantum classical correspondence,
that's a correspondence

718

00:27:12,530 --> 00:27:16,063

that's why is an active area
of research actually like,

719

00:27:17,220 --> 00:27:21,670

and we don't have an answer
to that, I guess why.

720

00:27:21,670 --> 00:27:23,740

- Maybe my follow up question is then

721

00:27:23,740 --> 00:27:27,110
it's for decades, people have
been working on this challenge

722

00:27:27,110 --> 00:27:28,513
and it's a big challenge.

723

00:27:29,756 --> 00:27:32,040
Is it not daunting as a scientist

724

00:27:32,040 --> 00:27:34,880
to take on challenges that are so

725

00:27:34,880 --> 00:27:36,630
unsolved for so many years?

726

00:27:36,630 --> 00:27:39,350
- So it is unsolved for so many years,

727

00:27:39,350 --> 00:27:42,020
but it's not like no
progress have been made.

728

00:27:42,020 --> 00:27:44,210
Like there have been so many

729

00:27:44,210 --> 00:27:47,680
different kinds of properties that we see.

730

00:27:47,680 --> 00:27:49,310
Like we can classify systems,

731

00:27:49,310 --> 00:27:51,520
whether they're using classical mechanics,

732

00:27:51,520 --> 00:27:53,090

whether they're integrable or not,

733

00:27:53,090 --> 00:27:55,630

or chaotic or not,

734

00:27:55,630 --> 00:27:57,970

depending on like, whether it,

735

00:27:57,970 --> 00:28:00,590

whether the system has a classical analog.

736

00:28:00,590 --> 00:28:03,050

So there are several quantum properties

737

00:28:03,050 --> 00:28:04,810

that people have come up with

738

00:28:04,810 --> 00:28:06,690

in these studies

739

00:28:06,690 --> 00:28:09,470

where they see that

they behave differently

740

00:28:09,470 --> 00:28:12,313

when the classical analog

is integrable or chaotic.

741

00:28:13,170 --> 00:28:15,070

But all of these properties,

742

00:28:15,070 --> 00:28:18,900

what we have found is

there is some exception

743

00:28:18,900 --> 00:28:20,843

and physics is a study.

744

00:28:20,843 --> 00:28:22,843
Physics is a, is a like,

745
00:28:24,130 --> 00:28:24,980
field where

746
00:28:26,180 --> 00:28:27,860
most of the innovations happen

747
00:28:27,860 --> 00:28:29,550
when we see an exception, actually

748
00:28:29,550 --> 00:28:32,600
like if we had thought of
what the photoelectric effect,

749
00:28:32,600 --> 00:28:34,300
as an exception, study it separately,

750
00:28:34,300 --> 00:28:37,480
that it doesn't follow the
rule of classical physics.

751
00:28:37,480 --> 00:28:39,760
We wouldn't have this third theory

752
00:28:39,760 --> 00:28:41,830
of quantum mechanics now, right?

753
00:28:41,830 --> 00:28:43,830
So whenever you see an exception,

754
00:28:43,830 --> 00:28:45,740
that is the area of growth.

755
00:28:45,740 --> 00:28:50,220
So like, so many advances have happened,

756

00:28:50,220 --> 00:28:53,860
but we still do not have a single answer.

757
00:28:53,860 --> 00:28:57,650
And there is a possibility
that after a few more years

758
00:28:57,650 --> 00:29:00,070
or after a couple of decades or something,

759
00:29:00,070 --> 00:29:01,920
there are so many pieces of this puzzles

760
00:29:01,920 --> 00:29:02,930
that people have found.

761
00:29:02,930 --> 00:29:06,608
There will be someone who
can glue all of them together

762
00:29:06,608 --> 00:29:08,368
and find an answer.

763
00:29:08,368 --> 00:29:09,963
– Might it be you?

764
00:29:09,963 --> 00:29:11,593
– Hopefully.

765
00:29:11,593 --> 00:29:13,620
– Is that a hope that,

766
00:29:13,620 --> 00:29:16,620
a sort of professional
goal that over your career,

767
00:29:16,620 --> 00:29:20,853
you will move this field
forward a certain amount?

768

00:29:20,853 --> 00:29:24,643
- I mean, I started my research
with that goal actually,

769

00:29:25,640 --> 00:29:27,900
and I have made small progress

770

00:29:27,900 --> 00:29:30,580
in some of the questions
or the conflicting answers.

771

00:29:30,580 --> 00:29:33,860
And I hope that that is
the big goal, actually,

772

00:29:33,860 --> 00:29:35,270
that I hope someday

773

00:29:35,270 --> 00:29:39,320
if I can answer how quantum
classical correspondence happens

774

00:29:39,320 --> 00:29:40,490
in chaotic systems.

775

00:29:40,490 --> 00:29:42,700
Like that is a big goal.
- Yeah.

776

00:29:42,700 --> 00:29:44,384
- I hope someday.

777

00:29:44,384 --> 00:29:46,780
If possible, me, that's fine.

778

00:29:46,780 --> 00:29:50,700
Like otherwise someone
answers that question.

779

00:29:50,700 --> 00:29:51,890

- And so why did you choose

780

00:29:51,890 --> 00:29:54,440

to come here to the Perimeter Institute

781

00:29:54,440 --> 00:29:57,170

to kind of help make progress

782

00:29:57,170 --> 00:29:58,747

towards entering that question?

783

00:29:58,747 --> 00:30:00,600

- Perimeter Institute is a place

784

00:30:00,600 --> 00:30:02,460

where like there's so many,

785

00:30:02,460 --> 00:30:04,120

it's a theoretical physics place

786

00:30:04,120 --> 00:30:07,340

and being a theoretical
physicist, like a perfect place.

787

00:30:07,340 --> 00:30:09,760

And then other thing is like,

788

00:30:09,760 --> 00:30:13,030

there are so many different
areas of research here and

789

00:30:13,910 --> 00:30:17,590

people like so freely collaborate with

790

00:30:17,590 --> 00:30:19,640

other people in other areas.

791

00:30:19,640 --> 00:30:22,760

And these intersections are
most interesting actually.

792

00:30:22,760 --> 00:30:24,810

Like I started my PhD,

793

00:30:24,810 --> 00:30:26,720

I wanted to work in quantum chaos,

794

00:30:26,720 --> 00:30:28,713

but then my advisor

795

00:30:28,713 --> 00:30:30,140

had worked

796

00:30:31,020 --> 00:30:33,070

in quantum information.

797

00:30:33,070 --> 00:30:35,610

So she gave me like this

798

00:30:36,780 --> 00:30:38,150

problem of

799

00:30:39,010 --> 00:30:40,510

understanding quantum chaos

800

00:30:40,510 --> 00:30:43,410

through this quantum information
perspective, actually.

801

00:30:43,410 --> 00:30:46,390

And then I got into the
field of quantum information

802

00:30:46,390 --> 00:30:49,980

and then here, like we
have different fields.

803

00:30:49,980 --> 00:30:54,890
Like I have collaborations with
other postdocs and quantum,

804

00:30:54,890 --> 00:30:57,510
quantum foundations and condensed matter.

805

00:30:57,510 --> 00:30:59,940
So those intersections
are really interesting

806

00:30:59,940 --> 00:31:01,760
finding people from other areas.

807

00:31:01,760 --> 00:31:03,537
And it's a very active
place in the sense that

808

00:31:03,537 --> 00:31:06,710
there are so many visitors

809

00:31:06,710 --> 00:31:09,350
from all around the world, actually like

810

00:31:09,350 --> 00:31:11,580
giving talks on so many different topics.

811

00:31:11,580 --> 00:31:14,690
So using techniques

812

00:31:14,690 --> 00:31:16,100
and tools from one

813

00:31:17,070 --> 00:31:18,700
branch to other branch,

814
00:31:18,700 --> 00:31:21,690
that's where I think

815
00:31:21,690 --> 00:31:24,040
sometimes major innovations happen.

816
00:31:24,040 --> 00:31:25,980
For example, like quantum,

817
00:31:25,980 --> 00:31:29,670
quantum information is one
thing that has led to like

818
00:31:29,670 --> 00:31:31,630
the tools and techniques
in quantum information

819
00:31:31,630 --> 00:31:33,620
has been used from condensed matter

820
00:31:33,620 --> 00:31:35,530
to high energy physics, actually,

821
00:31:35,530 --> 00:31:36,680
like black holes also,

822
00:31:36,680 --> 00:31:39,480
you have this black hole
information paradox or something.

823
00:31:39,480 --> 00:31:40,430
And in condensed matter,

824
00:31:40,430 --> 00:31:43,171
you have these questions
about thermalization,

825
00:31:43,171 --> 00:31:46,440

(mumbles), and where tools and techniques

826

00:31:46,440 --> 00:31:48,270

from quantum information have been used

827

00:31:48,270 --> 00:31:49,840

to answer some of the questions.

828

00:31:49,840 --> 00:31:52,207

So these intersections
are really interesting

829

00:31:52,207 --> 00:31:54,051

and that happen a lot at parameters.

830

00:31:54,051 --> 00:31:55,309

So I'm really excited to be here

831

00:31:55,309 --> 00:31:57,790

and collaborate with other people.

832

00:31:57,790 --> 00:31:58,980

- Yeah.

- That's fantastic.

833

00:31:58,980 --> 00:32:00,260

I was just,

834

00:32:00,260 --> 00:32:01,140

I wanted to ask

835

00:32:01,140 --> 00:32:02,910

a little bit further back in your past.

836

00:32:02,910 --> 00:32:04,350

Were you always,

837

00:32:04,350 --> 00:32:05,570

since you were a little kid,

838

00:32:05,570 --> 00:32:07,267
interested in quantum physics?

839

00:32:07,267 --> 00:32:11,410
How did you find this career path?

840

00:32:11,410 --> 00:32:15,010
– It started in my high
school that I became,

841

00:32:15,010 --> 00:32:16,763
became fascinated with physics.

842

00:32:16,763 --> 00:32:19,510
I think in my primary school,

843

00:32:19,510 --> 00:32:22,120
I was more interested in maths.

844

00:32:22,120 --> 00:32:25,040
I think I had an analytical
mind and always took a,

845

00:32:25,040 --> 00:32:28,740
a delight in like solving problems,

846

00:32:28,740 --> 00:32:30,393
difficult problems actually, like.

847

00:32:30,393 --> 00:32:33,100
– I read that you would solve problems,

848

00:32:33,100 --> 00:32:35,140
logic problems from a magazine.

849

00:32:35,140 --> 00:32:36,380

- Yeah, that's right.

850

00:32:36,380 --> 00:32:38,540

- Yeah, just on your own, just for fun?

851

00:32:38,540 --> 00:32:40,360

- Yeah, it was mostly for fun.

852

00:32:40,360 --> 00:32:43,790

I had elder siblings who were preparing

853

00:32:43,790 --> 00:32:45,590

for general competitive exams

854

00:32:45,590 --> 00:32:48,680

in which there were maths and
logical questions actually.

855

00:32:48,680 --> 00:32:51,950

And it was a fun to see
whether I could solve them

856

00:32:51,950 --> 00:32:52,783

in my school.

857

00:32:52,783 --> 00:32:54,070

So that happened.

858

00:32:54,070 --> 00:32:55,640

And then in my high school,

859

00:32:55,640 --> 00:32:59,980

preparing for a national level
engineering entrance exam.

860

00:32:59,980 --> 00:33:02,210

And in that, in that exam,

861

00:33:02,210 --> 00:33:06,650
basically problems that were
there were very complex.

862
00:33:06,650 --> 00:33:08,290
Like it was not just formula based

863
00:33:08,290 --> 00:33:10,110
that you are given a problem

864
00:33:10,110 --> 00:33:11,540
and you have these variables

865
00:33:11,540 --> 00:33:12,420
and this is the formula,

866
00:33:12,420 --> 00:33:15,353
you plug in the variable
values and you get the answer.

867
00:33:15,353 --> 00:33:18,600
That is not the kind
of questions, like it.

868
00:33:18,600 --> 00:33:21,540
You had to think from first
principles actually to,

869
00:33:21,540 --> 00:33:23,380
to solve those complex problem.

870
00:33:23,380 --> 00:33:26,230
So I was preparing for that exam

871
00:33:26,230 --> 00:33:29,060
and I had joined a coaching class,

872
00:33:29,060 --> 00:33:32,070
which was very usual back in India.

873

00:33:32,070 --> 00:33:34,730
- Coaching for this particular
exam, like tutoring,

874

00:33:34,730 --> 00:33:36,033
to learn how to take the exam?

875

00:33:36,033 --> 00:33:37,320
- High school students,

876

00:33:37,320 --> 00:33:40,230
one thing is you have to give
school exams like board exams.

877

00:33:40,230 --> 00:33:42,830
And then another thing is you
have to get into a college

878

00:33:42,830 --> 00:33:44,900
or university after that.

879

00:33:44,900 --> 00:33:47,311
So these national and level entrance exam,

880

00:33:47,311 --> 00:33:49,150
these coaching classes,

881

00:33:49,150 --> 00:33:51,270
they taught things

882

00:33:51,270 --> 00:33:53,080
at a more fundamental level.

883

00:33:53,080 --> 00:33:56,910
Like board exams was slightly
simpler in the sense that

884

00:33:56,910 --> 00:33:58,810
as I said, you can have variables

885
00:33:58,810 --> 00:34:00,600
and plug in a formula line
and you will get answer,

886
00:34:00,600 --> 00:34:02,760
but to crack these entrance exams,

887
00:34:02,760 --> 00:34:05,240
you really needed to think
for, from first principal.

888
00:34:05,240 --> 00:34:06,550
So the teacher,

889
00:34:06,550 --> 00:34:09,750
like my physics teacher in my high school,

890
00:34:09,750 --> 00:34:10,920
in my coaching class

891
00:34:10,920 --> 00:34:13,583
played a very, very big role, I would say,

892
00:34:13,583 --> 00:34:15,520
where I became fascinated with physics

893
00:34:15,520 --> 00:34:18,040
because he taught us how to think

894
00:34:18,040 --> 00:34:21,050
from first principles,
like given a problem,

895
00:34:21,050 --> 00:34:23,050
which seemed very complex
in the first place.

896

00:34:23,050 --> 00:34:25,780

And I would be like, there's
no way I can solve it.

897

00:34:25,780 --> 00:34:28,250

And then when you start
with these first principles,

898

00:34:28,250 --> 00:34:30,710

just like the very basic equation,

899

00:34:30,710 --> 00:34:32,930

which is, I think it was to Newton,

900

00:34:32,930 --> 00:34:34,850

Newton's second law.

901

00:34:34,850 --> 00:34:36,740

If you understood this equation well,

902

00:34:36,740 --> 00:34:40,330

there was so many types of
problems that you can solve,

903

00:34:40,330 --> 00:34:41,830

very complex problems.

904

00:34:41,830 --> 00:34:43,273

And just seeing that,

905

00:34:44,180 --> 00:34:48,060

that everything combines
together in this simple equation

906

00:34:48,060 --> 00:34:51,160

and you can solve difficult problems,

907

00:34:51,160 --> 00:34:53,830
seemingly unsolvable in the first place,

908
00:34:53,830 --> 00:34:57,000
that gave me another level
of delight, I suppose.

909
00:34:57,000 --> 00:34:58,230
And I enjoyed this

910
00:34:58,230 --> 00:35:01,490
and the way my teacher taught,

911
00:35:01,490 --> 00:35:03,360
I really imagined myself like,

912
00:35:03,360 --> 00:35:06,200
I felt like I wish I could
develop some of these equations

913
00:35:06,200 --> 00:35:07,539
or something like that.

914
00:35:07,539 --> 00:35:09,299
That was so fundamental using,

915
00:35:09,299 --> 00:35:12,010
which you can explain so much,

916
00:35:12,010 --> 00:35:13,882
so many phenomena in the world.

917
00:35:13,882 --> 00:35:18,690
So that really made me
think that I wish, I mean,

918
00:35:18,690 --> 00:35:21,916
pursue this research
career in the first place.

919

00:35:21,916 --> 00:35:23,290

- And where did you go from there?

920

00:35:23,290 --> 00:35:25,940

You went to undergraduate studies.

921

00:35:25,940 --> 00:35:30,480

- Yeah, so I cracked that engineering exam, national level.

922

00:35:30,480 --> 00:35:33,070

- Yes, you told us, I believe,

923

00:35:33,070 --> 00:35:35,880

of the 400,000 people that took that exam,

924

00:35:35,880 --> 00:35:38,135

you're in the top, what, one, 2%.

925

00:35:38,135 --> 00:35:39,133

- Two top 2%.

926

00:35:39,133 --> 00:35:40,950

- So you weren't gonna mention that on your own,

927

00:35:40,950 --> 00:35:42,890

'cause you were being too humble, but she,

928

00:35:42,890 --> 00:35:45,263

she aced the exam, then what happened?

929

00:35:46,620 --> 00:35:49,530

- Yeah, so I was able to crack that exam

930

00:35:49,530 --> 00:35:54,050

and then I went to an

engineering institute

931

00:35:54,050 --> 00:35:55,920

and I was there for a year,

932

00:35:55,920 --> 00:36:00,340

but somehow I didn't feel

quite at place there.

933

00:36:00,340 --> 00:36:01,400

Like,

934

00:36:01,400 --> 00:36:02,970

and I didn't,

935

00:36:02,970 --> 00:36:05,300

couldn't picture myself

becoming a researcher

936

00:36:05,300 --> 00:36:06,240

after studying there.

937

00:36:06,240 --> 00:36:07,440

I don't know why.

938

00:36:07,440 --> 00:36:09,740

I just didn't feel like it.

939

00:36:09,740 --> 00:36:12,620

I still tried to understand

why that happened.

940

00:36:12,620 --> 00:36:16,354

And at the age of like 18

or something like that,

941

00:36:16,354 --> 00:36:20,670

deciding to put a place like

that and go to a new college

942
00:36:20,670 --> 00:36:22,970
was a risky decision,

943
00:36:22,970 --> 00:36:24,820
not supported by many,

944
00:36:24,820 --> 00:36:28,130
but I was not feeling
at home at that place.

945
00:36:28,130 --> 00:36:33,130
And then I wrote an exam
for another institute,

946
00:36:33,340 --> 00:36:36,200
undergrad institute, which
was more research focused.

947
00:36:36,200 --> 00:36:37,740
I qualified that exam.

948
00:36:37,740 --> 00:36:40,440
So I went ahead joining
the other institute

949
00:36:40,440 --> 00:36:44,670
where I did a bachelor's
degree in physics.

950
00:36:44,670 --> 00:36:46,530
– And I really wanna ask
something here because

951
00:36:46,530 --> 00:36:48,935
for those who might
not know, I know Meenu,

952
00:36:48,935 --> 00:36:50,260

you wrote such a really nice article

953

00:36:50,260 --> 00:36:52,027

as part of this story,

954

00:36:52,027 --> 00:36:54,330

"What is it like to be

a woman in physics,"

955

00:36:54,330 --> 00:36:55,830

which is a collection of stories

956

00:36:55,830 --> 00:36:57,797

by women here at Perimeter Institute.

957

00:36:57,797 --> 00:37:01,040

And I just wrote down one

of my favorite quotes.

958

00:37:01,040 --> 00:37:01,920

You said,

959

00:37:01,920 --> 00:37:03,940

it was not normal for a small town girl

960

00:37:03,940 --> 00:37:05,760

from a conservative society like me

961

00:37:05,760 --> 00:37:08,180

to leave home for undergraduate studies,

962

00:37:08,180 --> 00:37:10,580

let alone later travel

to a foreign country

963

00:37:10,580 --> 00:37:11,950

for graduate studies.

964

00:37:11,950 --> 00:37:14,250

And the rest of your
story is really great too.

965

00:37:14,250 --> 00:37:15,110

And I just was wondering

966

00:37:15,110 --> 00:37:17,530

if you can kind of speak
to that piece a little bit.

967

00:37:17,530 --> 00:37:19,350

What was it like to make that decision

968

00:37:19,350 --> 00:37:22,630

to challenge those societal norms?

969

00:37:22,630 --> 00:37:26,180

- I was very scared in
my school time actually.

970

00:37:26,180 --> 00:37:29,210

Like I was seeing most of the women

971

00:37:29,210 --> 00:37:30,870

around struggling actually.

972

00:37:30,870 --> 00:37:35,370

Like I have a bunch of like
very strong-headed women around

973

00:37:35,370 --> 00:37:37,870

in my back in my family,
or extended family,

974

00:37:37,870 --> 00:37:42,870

but I still see that trying
to break any social norm.

975

00:37:42,940 --> 00:37:45,490
Like they have to put so much effort.

976
00:37:45,490 --> 00:37:48,397
And after putting in so much
effort, little by little,

977
00:37:48,397 --> 00:37:51,310
it breaks them down somewhere actually.

978
00:37:51,310 --> 00:37:55,160
And that hard life that I was seeing,

979
00:37:55,160 --> 00:37:57,340
all of them living,

980
00:37:57,340 --> 00:38:01,283
I felt like I really need
to have a better life,

981
00:38:02,140 --> 00:38:04,860
which I can live on my own terms.

982
00:38:04,860 --> 00:38:09,430
It was not normal for families
back in those days actually

983
00:38:09,430 --> 00:38:11,040
to send their girl,

984
00:38:11,040 --> 00:38:14,810
girl child to study outside
of the hometown, actually.

985
00:38:14,810 --> 00:38:16,470
It was not considered safe or something.

986
00:38:16,470 --> 00:38:19,058
It's norm, it's relatively normal now.

987

00:38:19,058 --> 00:38:22,650

But at, in those times
it was not that normal.

988

00:38:22,650 --> 00:38:26,730

If I could crack this
prestigious exam called ITJ,

989

00:38:26,730 --> 00:38:27,940

it was very prestigious

990

00:38:27,940 --> 00:38:30,250

and it would be a prestige for the family.

991

00:38:30,250 --> 00:38:34,330

They will be willing to send
me if I can crack this exam.

992

00:38:34,330 --> 00:38:37,570

So I put in a lot of hard work and effort

993

00:38:37,570 --> 00:38:39,140

and I was very, very scared.

994

00:38:39,140 --> 00:38:40,550

What if I couldn't crack it?

995

00:38:40,550 --> 00:38:43,277

Like I will be stuck here.

996

00:38:43,277 --> 00:38:45,930

But with hard work, I think hard,

997

00:38:45,930 --> 00:38:47,010

hard work and conviction,

998

00:38:47,010 --> 00:38:49,860

I was able to crack that
exam and leave home.

999

00:38:49,860 --> 00:38:53,010
So it was slightly difficult.

1000

00:38:53,010 --> 00:38:55,360
- And home, home is a relatively,

1001

00:38:55,360 --> 00:38:57,750
I think it's Gaia and India, Gaia.

1002

00:38:57,750 --> 00:38:58,900
- Yeah.
- It's,

1003

00:38:58,900 --> 00:39:00,750
it's more of a tourist place.

1004

00:39:00,750 --> 00:39:02,557
I think it's a spiritual destination

1005

00:39:02,557 --> 00:39:04,860
because there's connections to Buddhism.

1006

00:39:04,860 --> 00:39:07,270
- Yes, that's right.
- It's probably not a place

1007

00:39:07,270 --> 00:39:10,430
where a young girl says
I wanna be a physicist

1008

00:39:10,430 --> 00:39:12,115
and gets the warmest reception.

1009

00:39:12,115 --> 00:39:15,310
What kept you going when
there, you said you,

1010

00:39:15,310 --> 00:39:18,410
you met opposition at
stages along your way?

1011

00:39:18,410 --> 00:39:19,243
- First of all,

1012

00:39:19,243 --> 00:39:20,930
I really liked studying

1013

00:39:21,779 --> 00:39:24,470
and solving analytical
problems in physics and math.

1014

00:39:24,470 --> 00:39:25,650
That was one thing.

1015

00:39:25,650 --> 00:39:27,090
And the other thing was like

1016

00:39:27,090 --> 00:39:30,010
that conviction that I want a better life.

1017

00:39:30,010 --> 00:39:32,770
So both of those things like,

1018

00:39:32,770 --> 00:39:33,810
and the third thing,

1019

00:39:33,810 --> 00:39:36,679
like I really got amazing teachers

1020

00:39:36,679 --> 00:39:41,000
like these coaching
classes I am telling about,

1021

00:39:41,000 --> 00:39:42,980

like I had three different teachers

1022

00:39:42,980 --> 00:39:45,513

who were extremely
supportive, always there.

1023

00:39:46,460 --> 00:39:48,830

Taking classes from them
really, really helped.

1024

00:39:48,830 --> 00:39:51,660

And they were there to answer my questions

1025

00:39:51,660 --> 00:39:54,600

or support me in any way they can.

1026

00:39:54,600 --> 00:39:58,500

So their presence meant
a lot at that time,

1027

00:39:58,500 --> 00:39:59,890

actually their belief in me

1028

00:39:59,890 --> 00:40:03,360

that I can do something,
I can crack this exam,

1029

00:40:03,360 --> 00:40:04,900

even though it is difficult,

1030

00:40:04,900 --> 00:40:06,210

that really helped.

1031

00:40:06,210 --> 00:40:08,760

Due to those factors,
I was able to make it.

1032

00:40:08,760 --> 00:40:10,490

- And moving, you know,

1033
00:40:10,490 --> 00:40:12,930
from a small hometown to another city,

1034
00:40:12,930 --> 00:40:15,560
let alone a country on the
other side of the world,

1035
00:40:15,560 --> 00:40:16,809
that was a big,

1036
00:40:16,809 --> 00:40:20,130
was that moving to Canada to do grad,

1037
00:40:20,130 --> 00:40:22,060
to do a PhD,

1038
00:40:22,060 --> 00:40:23,893
was that a,

1039
00:40:23,893 --> 00:40:25,197
a difficult leap for you to make

1040
00:40:25,197 --> 00:40:26,840
or was that always in the cards

1041
00:40:26,840 --> 00:40:28,890
that you would go somewhere to,

1042
00:40:28,890 --> 00:40:30,440
somewhere else to become a researcher?

1043
00:40:30,440 --> 00:40:33,110
– I don't exactly remember
when was the first time

1044
00:40:33,110 --> 00:40:36,514
I really thought that I could

go to a different country

1045

00:40:36,514 --> 00:40:39,580

and live by myself and study on my own.

1046

00:40:39,580 --> 00:40:40,633

That was,

1047

00:40:41,520 --> 00:40:44,450

that was not something that

I thought from the beginning,

1048

00:40:44,450 --> 00:40:46,210

but then in my college,

1049

00:40:46,210 --> 00:40:47,480

like I was the third batch,

1050

00:40:47,480 --> 00:40:49,480

there were two more senior batches than me

1051

00:40:49,480 --> 00:40:52,160

and I was seeing other students,

1052

00:40:52,160 --> 00:40:54,350

including women, going out

1053

00:40:54,350 --> 00:40:56,760

to other countries for research projects,

1054

00:40:56,760 --> 00:40:59,320

summer internships or

for graduate studies.

1055

00:40:59,320 --> 00:41:01,950

And I just felt like if

they could do it, I'll,

1056

00:41:01,950 --> 00:41:03,270
I'll be also able to do it.

1057
00:41:03,270 --> 00:41:06,951
So I followed their footsteps in that way.

1058
00:41:06,951 --> 00:41:08,657
So, yeah.

1059
00:41:08,657 --> 00:41:10,577
- And you created your own footsteps too,

1060
00:41:10,577 --> 00:41:12,570
you know, for others to follow.

1061
00:41:12,570 --> 00:41:13,420
- Yeah, hopefully

1062
00:41:13,420 --> 00:41:15,630
it will inspire others as well.

1063
00:41:15,630 --> 00:41:16,500
- It's interesting, right.

1064
00:41:16,500 --> 00:41:18,580
I think for so many people

1065
00:41:18,580 --> 00:41:21,020
it's so important to have
those role models, right?

1066
00:41:21,020 --> 00:41:24,450
Whether they be your colleagues
that are a year ahead of you

1067
00:41:24,450 --> 00:41:27,040
or somebody that's maybe
already a professional

1068
00:41:27,040 --> 00:41:27,873
in the field.

1069
00:41:27,873 --> 00:41:29,640
Was it important to you to have

1070
00:41:29,640 --> 00:41:32,092
role models at maybe different
levels along the way?

1071
00:41:32,092 --> 00:41:32,925
- Yeah.

1072
00:41:32,925 --> 00:41:36,870
So my first role model I
would say is Kalpana Chawla.

1073
00:41:36,870 --> 00:41:38,540
Unfortunately she is no more.

1074
00:41:38,540 --> 00:41:40,130
So Kalpana Chawla,

1075
00:41:40,130 --> 00:41:45,130
she was the first Indian
woman to go to moon,

1076
00:41:46,311 --> 00:41:49,490
actually during her second trip to moon,

1077
00:41:49,490 --> 00:41:51,430
there was a crash

1078
00:41:51,430 --> 00:41:55,260
in that shuttle and unfortunately
they all passed away.

1079
00:41:55,260 --> 00:41:58,080

So yeah, she was a big role model for me.

1080

00:41:58,080 --> 00:42:02,890

Like she came from a small town

1081

00:42:02,890 --> 00:42:04,710

in another state in India,

1082

00:42:04,710 --> 00:42:06,550

which is Punjab,

1083

00:42:06,550 --> 00:42:10,020

and seeing her like reading her story,

1084

00:42:10,020 --> 00:42:11,620

knowing about her.

1085

00:42:11,620 --> 00:42:14,520

I felt like if I followed her footsteps,

1086

00:42:14,520 --> 00:42:18,110

I could do something as big as her.

1087

00:42:18,110 --> 00:42:19,646

So that was really important.

1088

00:42:19,646 --> 00:42:20,720

Looking back, I,

1089

00:42:20,720 --> 00:42:23,550

I can never think that I
could have looked up to Neil,

1090

00:42:23,550 --> 00:42:25,410

Neil Armstrong for example,

1091

00:42:25,410 --> 00:42:28,610

and thought that I could

have done something similar

1092

00:42:28,610 --> 00:42:29,770
or something like that.

1093

00:42:29,770 --> 00:42:33,120
But having someone who has same gender,

1094

00:42:33,120 --> 00:42:35,580
same ethnicity, same
back family background,

1095

00:42:35,580 --> 00:42:38,540
like similar kind of family background.

1096

00:42:38,540 --> 00:42:40,800
And you can dream big

1097

00:42:40,800 --> 00:42:43,110
if you see some other people

1098

00:42:43,110 --> 00:42:44,890
with similar situation

1099

00:42:44,890 --> 00:42:47,010
dreaming big and being able to make it.

1100

00:42:47,010 --> 00:42:48,120
So in my childhood,

1101

00:42:48,120 --> 00:42:50,550
I always dreamed off
becoming an astronaut,

1102

00:42:50,550 --> 00:42:52,770
just like Kalpana Chawla,

1103

00:42:52,770 --> 00:42:54,070

changed over time.

1104

00:42:54,070 --> 00:42:57,770

But I think her presence

1105

00:42:57,770 --> 00:42:59,590

and whatever she achieved in her life,

1106

00:42:59,590 --> 00:43:04,310

knowing that helped me dream

big, at least in my life.

1107

00:43:04,310 --> 00:43:05,143

- Yeah, that's amazing.

1108

00:43:05,143 --> 00:43:06,200

- Amazing.

1109

00:43:06,200 --> 00:43:07,033

- Would you,

1110

00:43:07,033 --> 00:43:08,700

if someone offered you

a chance to go to space,

1111

00:43:08,700 --> 00:43:10,690

now that space tourism is a thing,

1112

00:43:10,690 --> 00:43:11,940

would you wanna be an astronaut still?

1113

00:43:11,940 --> 00:43:15,180

- I think I'm less of a tourist

1114

00:43:15,180 --> 00:43:17,440

and more of a person from research.

1115

00:43:17,440 --> 00:43:21,230

Like if it was more of an
opportunity to go there

1116

00:43:21,230 --> 00:43:23,270
from a research point of view,

1117

00:43:23,270 --> 00:43:24,740
I think I would be more interested

1118

00:43:24,740 --> 00:43:27,260
rather than just going
there and seeing things,

1119

00:43:27,260 --> 00:43:28,470
how it looks like.

1120

00:43:28,470 --> 00:43:30,880
- If you did have to now
say what's your dream,

1121

00:43:30,880 --> 00:43:31,713
what would it be?

1122

00:43:31,713 --> 00:43:35,850
Would it be to crack this
quantum classical correspondence?

1123

00:43:35,850 --> 00:43:38,350
- If I could play

1124

00:43:38,350 --> 00:43:40,930
good enough role in
tracking that question,

1125

00:43:40,930 --> 00:43:42,820
that would be really nice.

1126

00:43:42,820 --> 00:43:44,140
But apart from that,

1127

00:43:44,140 --> 00:43:47,470
like all these innovations
happening in quantum computing,

1128

00:43:47,470 --> 00:43:49,890
I keep on thinking to the day, like, it,

1129

00:43:49,890 --> 00:43:52,800
sometimes it seems like it is a big dream,

1130

00:43:52,800 --> 00:43:54,220
which may or may not happen.

1131

00:43:54,220 --> 00:43:55,970
But then I keep on thinking that

1132

00:43:55,970 --> 00:43:59,150
about the time when classical
computers were devised,

1133

00:43:59,150 --> 00:44:00,453
like the first computer

1134

00:44:00,453 --> 00:44:02,919
were like the size of a big room.

1135

00:44:02,919 --> 00:44:06,201
And now it's like in our hand.
- Yeah.

1136

00:44:06,201 --> 00:44:09,070
And actually at the Institute
for Quantum Computing

1137

00:44:09,070 --> 00:44:10,070
where you were,

1138

00:44:10,070 --> 00:44:11,810
some of the quantum computers,

1139
00:44:11,810 --> 00:44:13,090
there are the size of a room.

1140
00:44:13,090 --> 00:44:14,340
It's, it's a,

1141
00:44:14,340 --> 00:44:15,342
it's a similar analogy there.
- Yeah.

1142
00:44:15,342 --> 00:44:18,410
- Quantum computing is sort
of at that infancy stage,

1143
00:44:18,410 --> 00:44:19,750
but you can see the,

1144
00:44:19,750 --> 00:44:22,000
the potential and you
got to work right in the,

1145
00:44:22,000 --> 00:44:24,798
in the middle of a quantum
computing research center.

1146
00:44:24,798 --> 00:44:25,760
- Yes, that's right.
- Well, I,

1147
00:44:25,760 --> 00:44:27,540
I love the way you put it earlier, too,

1148
00:44:27,540 --> 00:44:29,920
that sometimes doing research

1149
00:44:29,920 --> 00:44:31,050

involves putting together

1150

00:44:31,050 --> 00:44:33,300

so many little pieces of a puzzle, right.

1151

00:44:33,300 --> 00:44:34,780

And you have these pieces.

1152

00:44:34,780 --> 00:44:37,250

It's not always obvious
how they fit together

1153

00:44:37,250 --> 00:44:39,810

and it's not always obvious
how many pieces there are,

1154

00:44:39,810 --> 00:44:41,530

how long it's gonna take
to put them together.

1155

00:44:41,530 --> 00:44:44,730

But I think even figuring
out how to glue together

1156

00:44:44,730 --> 00:44:46,710

two pieces is,

1157

00:44:46,710 --> 00:44:48,450

is a big accomplishment
in many cases, right.

1158

00:44:48,450 --> 00:44:49,390

- Yeah.

1159

00:44:49,390 --> 00:44:52,160

- I'm curious to know if
you still have that same joy

1160

00:44:52,160 --> 00:44:55,030

that you felt when you
were a kid solving puzzles.

1161

00:44:55,030 --> 00:44:57,630

If doing math and solving
difficult problems,

1162

00:44:57,630 --> 00:44:58,470

is it still fun?

1163

00:44:58,470 --> 00:45:02,410

Is it still like a hobby for
you the way it was as a child?

1164

00:45:02,410 --> 00:45:05,020

- Yeah, like whenever I get any new idea,

1165

00:45:05,020 --> 00:45:07,410

I'm very excited to try it out,

1166

00:45:07,410 --> 00:45:08,667

whether it'll work or not.

1167

00:45:08,667 --> 00:45:11,940

That's the most exciting
part of my research projects.

1168

00:45:11,940 --> 00:45:14,500

Like, and these ideas
just happen to come around

1169

00:45:14,500 --> 00:45:17,670

like while I'm doing some stuff,

1170

00:45:17,670 --> 00:45:20,550

which doesn't require a lot
of attention, for example,

1171

00:45:20,550 --> 00:45:22,730

washing dishes or cooking
or something like that, or,

1172

00:45:22,730 --> 00:45:26,650
or waiting at the bus stop for the bus.

1173

00:45:26,650 --> 00:45:28,760
So these are the moments when

1174

00:45:28,760 --> 00:45:31,200
some ideas will just come to my mind

1175

00:45:31,200 --> 00:45:32,912
and then I'm so excited to try it out,

1176

00:45:32,912 --> 00:45:34,783
whether that will work or not.

1177

00:45:35,669 --> 00:45:38,840
And that is the most joyous part of

1178

00:45:38,840 --> 00:45:40,400
being a researcher for me.

1179

00:45:40,400 --> 00:45:42,410
- Interesting, even if
it doesn't work out,

1180

00:45:42,410 --> 00:45:46,220
even if the idea falls
flat and doesn't pan out?

1181

00:45:46,220 --> 00:45:50,410
- So as long as a few ideas
are working out out of many,

1182

00:45:50,410 --> 00:45:53,781
like as long as two or two
ideas are working out out of 10,

1183

00:45:53,781 --> 00:45:56,420
suppose, that's fine.

1184

00:45:56,420 --> 00:45:59,300
It will be a little frustrating if

1185

00:45:59,300 --> 00:46:01,525
I thought of 10 ideas
and nothing worked out.

1186

00:46:01,525 --> 00:46:02,780
(laughs)

1187

00:46:02,780 --> 00:46:04,624
But luckily,

1188

00:46:04,624 --> 00:46:05,897
if I think of 10 ideas,

1189

00:46:05,897 --> 00:46:08,910
two to three ideas turn out to work so.

1190

00:46:08,910 --> 00:46:11,240
– Trial and error only works
when there's some error.

1191

00:46:11,240 --> 00:46:13,370
So yeah, you need to.
– Yeah.

1192

00:46:13,370 --> 00:46:15,245
– Well, Meenu, we now
wanna take some questions

1193

00:46:15,245 --> 00:46:17,050
if that's okay.

1194

00:46:17,050 --> 00:46:19,210
So we, you know, as part of this,

1195
00:46:19,210 --> 00:46:21,840
we wanna see what other
people wanna ask you as well.

1196
00:46:21,840 --> 00:46:23,580
And so we have a question today

1197
00:46:23,580 --> 00:46:25,340
that was actually sent in by a student

1198
00:46:25,340 --> 00:46:28,060
from our PSI program here
at Perimeter Institute.

1199
00:46:28,060 --> 00:46:30,090
So for those that might not know,

1200
00:46:30,090 --> 00:46:32,845
PSI is a one year master's
program in theoretical physics

1201
00:46:32,845 --> 00:46:34,410
here at Perimeter Institute.

1202
00:46:34,410 --> 00:46:35,930
I actually teach in that program.

1203
00:46:35,930 --> 00:46:38,780
I teach lectures in quantum
science and machine learning.

1204
00:46:38,780 --> 00:46:40,570
So we have a question here

1205
00:46:40,570 --> 00:46:43,560
that's from one of our

students named Anna Kinur.

1206

00:46:43,560 --> 00:46:46,110

– What does it mean to do research

1207

00:46:46,110 --> 00:46:48,173

through the lens of quantum information?

1208

00:46:49,270 --> 00:46:51,020

Do you really think the world

1209

00:46:51,020 --> 00:46:54,323

can be reduced to only information?

1210

00:46:54,323 --> 00:46:56,620

– First of all, thanks a lot, Anna, for that question.

1211

00:46:56,620 --> 00:46:59,180

That's a great question.

1212

00:46:59,180 --> 00:47:01,530

So the thing is in my research,

1213

00:47:01,530 --> 00:47:02,570

since I started my PhD,

1214

00:47:02,570 --> 00:47:05,573

I started working on quantum chaos

1215

00:47:05,573 --> 00:47:08,227

through the lens of quantum information.

1216

00:47:08,227 --> 00:47:11,980

So that has been a majority of my part in my research.

1217

00:47:11,980 --> 00:47:15,520

So I can't really speak of a general term,

1218

00:47:15,520 --> 00:47:17,630

in general terms, what it means to

1219

00:47:18,560 --> 00:47:21,820

research and from other perspectives,

1220

00:47:21,820 --> 00:47:23,144

a lot.

1221

00:47:23,144 --> 00:47:24,520

The thing is quantum information,

1222

00:47:24,520 --> 00:47:27,460

I see it as something that has

1223

00:47:27,460 --> 00:47:30,430

brought together different
fields in physics,

1224

00:47:30,430 --> 00:47:34,120

like it has provided a new
perspective in different fields.

1225

00:47:34,120 --> 00:47:36,720

For example, in condensed
matter to high energy physics,

1226

00:47:36,720 --> 00:47:39,610

which look like distinct topics, actually

1227

00:47:39,610 --> 00:47:40,630

in the first place.

1228

00:47:40,630 --> 00:47:43,920

Like if you go back like 30, 40 years ago,

1229

00:47:43,920 --> 00:47:44,880
all those physicists,

1230
00:47:44,880 --> 00:47:47,288
you can classify them as
condensed matter physicist

1231
00:47:47,288 --> 00:47:48,870
or high energy physicist.

1232
00:47:48,870 --> 00:47:49,927
But now that's not the case.

1233
00:47:49,927 --> 00:47:52,330
For example, I would talk about

1234
00:47:52,330 --> 00:47:54,550
a faculty here at Perimeter, Beni.

1235
00:47:54,550 --> 00:47:56,765
Like he works at so much, like he is,

1236
00:47:56,765 --> 00:47:59,920
he is very much into high.

1237
00:47:59,920 --> 00:48:01,930
- Beni Yoshida?
- Yeah.

1238
00:48:01,930 --> 00:48:02,858
- We know Beni.
- Jinx.

1239
00:48:02,858 --> 00:48:05,730
- Yeah, so he works very much
into high energy physics,

1240
00:48:05,730 --> 00:48:07,120
like black holes stuff,

1241
00:48:07,120 --> 00:48:08,660
as well as condensed matter physics.

1242
00:48:08,660 --> 00:48:10,150
And he is a faculty

1243
00:48:10,150 --> 00:48:12,420
in the quantum information research group,

1244
00:48:12,420 --> 00:48:15,780
looking at things from the
point of information perspective

1245
00:48:15,780 --> 00:48:18,180
gives us more pieces of the puzzle,

1246
00:48:18,180 --> 00:48:20,130
the bigger puzzle of physics actually.

1247
00:48:20,130 --> 00:48:21,520
And it definitely helps.

1248
00:48:21,520 --> 00:48:23,570
And maybe it'll be

1249
00:48:23,570 --> 00:48:27,630
piece that solves bigger
problems in physics, who knows.

1250
00:48:27,630 --> 00:48:29,380
– So it's not necessarily about

1251
00:48:29,380 --> 00:48:30,860
answering every possible question,

1252
00:48:30,860 --> 00:48:33,935
but giving a new way to look

at or a new perspective.

1253

00:48:33,935 --> 00:48:35,680

Yeah, oh, cool.

1254

00:48:35,680 --> 00:48:37,193

- To the existing problems,

1255

00:48:38,100 --> 00:48:39,900

other fields of physics actually.

1256

00:48:39,900 --> 00:48:41,590

So it's definitely an interesting way.

1257

00:48:41,590 --> 00:48:44,140

I have been working in
it for seven years now

1258

00:48:44,140 --> 00:48:45,520

since the start of my PhD

1259

00:48:45,520 --> 00:48:47,640

and I have really enjoyed it.

1260

00:48:47,640 --> 00:48:50,810

- I have a question from
someone named Ahmed,

1261

00:48:50,810 --> 00:48:52,870

a student here in Waterloo region,

1262

00:48:52,870 --> 00:48:55,570

and he asks why can't quantum mechanics

1263

00:48:55,570 --> 00:48:57,170

agree with relativity?

1264

00:48:57,170 --> 00:48:59,490

- Thanks, Ahmed for that question.

1265

00:48:59,490 --> 00:49:02,600

So thing is generally
a theory of relativity,

1266

00:49:02,600 --> 00:49:04,430

space time is continuum.

1267

00:49:04,430 --> 00:49:06,280

Energy is also continuous,

1268

00:49:06,280 --> 00:49:08,420

but in quantum mechanics,

1269

00:49:08,420 --> 00:49:10,550

space time is at equal footing

1270

00:49:10,550 --> 00:49:12,690

in general related theory of relativity

1271

00:49:12,690 --> 00:49:14,920

and energy is a continuous thing.

1272

00:49:14,920 --> 00:49:16,290

But in quantum mechanics,

1273

00:49:16,290 --> 00:49:17,300

at least in the starting,

1274

00:49:17,300 --> 00:49:19,330

if we talk about the starting or picture,

1275

00:49:19,330 --> 00:49:21,630

space and time are at different footing,

1276

00:49:21,630 --> 00:49:23,940

plus energy is discreet.

1277

00:49:23,940 --> 00:49:25,160

It is quantized.

1278

00:49:25,160 --> 00:49:26,890

And other thing is like,

1279

00:49:26,890 --> 00:49:31,360

we still do not have a
quantized period of gravity.

1280

00:49:31,360 --> 00:49:33,600

Like those pieces are required

1281

00:49:33,600 --> 00:49:35,391

such that we can glue together

1282

00:49:35,391 --> 00:49:38,160

general relativity and quantum physics.

1283

00:49:38,160 --> 00:49:39,810

- Is that quantum gravity that's--

1284

00:49:39,810 --> 00:49:42,380

- That's the bigger umbrella, yeah.

1285

00:49:42,380 --> 00:49:44,720

In which people are trying to figure out

1286

00:49:44,720 --> 00:49:46,370

how to quantize gravity

1287

00:49:46,370 --> 00:49:48,830

so that we will be able to
glue together these two fields.

1288

00:49:48,830 --> 00:49:51,420

- So there's a whole field of research

1289

00:49:51,420 --> 00:49:53,973

devoted to answering that
question, I guess, yeah.

1290

00:49:53,973 --> 00:49:57,348

– Many faculties here, I
guess working in that area.

1291

00:49:57,348 --> 00:49:59,477

– Well Meenu, you've been
so generous with your time

1292

00:49:59,477 --> 00:50:01,720

and it's been really
fascinating chatting with you.

1293

00:50:01,720 --> 00:50:02,860

Thank you for joining us.

1294

00:50:02,860 --> 00:50:03,980

It's been great.

1295

00:50:03,980 --> 00:50:04,813

– Yeah, thank you.

1296

00:50:04,813 --> 00:50:05,646

This has been just so much fun.

1297

00:50:05,646 --> 00:50:07,740

I've really enjoyed
learning more about you,

1298

00:50:07,740 --> 00:50:09,110

even though I've known you for years,

1299

00:50:09,110 --> 00:50:10,710

I've learned so much about you.

1300

00:50:10,710 --> 00:50:13,500

So thank you so much for
sharing your time with us.

1301

00:50:13,500 --> 00:50:16,308

- Thanks a lot, Lauren
and Colin, for having me.

1302

00:50:16,308 --> 00:50:18,891

(upbeat music)

1303

00:50:21,170 --> 00:50:23,710

- Thanks for stepping
inside the Perimeter.

1304

00:50:23,710 --> 00:50:25,160

If you like, what you hear,

1305

00:50:25,160 --> 00:50:26,950

please help us spread the word.

1306

00:50:26,950 --> 00:50:27,840

You can rate,

1307

00:50:27,840 --> 00:50:29,230

review and subscribe

1308

00:50:29,230 --> 00:50:31,000

to "Conversations at the Perimeter"

1309

00:50:31,000 --> 00:50:33,380

wherever you get your podcast.

1310

00:50:33,380 --> 00:50:35,520

Every review really helps us a lot

1311

00:50:35,520 --> 00:50:38,520

and it helps more science

enthusiasts find us.

1312

00:50:38,520 --> 00:50:40,527

Thank you for being part of the equation.

1313

00:50:40,527 --> 00:50:43,194

(upbeat music)