1
00:00:00,125 --> 00:00:02,708
(upbeat music)

2
00:00:08,910 --> 00:00:10,560
- Hello, everyone, and welcome back

3
00:00:10,560 --> 00:00:12,600
to Conversations at the Perimeter.

4
00:00:12,600 --> 00:00:14,280
On this episode, Lauren and I chat

5
00:00:14,280 --> 00:00:16,230
with Nicole Yunger Halpern.

6
00:00:16,230 --> 00:00:18,660
She is a quantum thermodynamicist,

7
00:00:18,660 --> 00:00:21,720
which is just about as
complicated as it sounds,

8
00:00:21,720 --> 00:00:25,020
but thankfully Nicole is
gifted at explaining it,

9
00:00:25,020 --> 00:00:27,540
and she's done so in the
context of steampunk,

10
00:00:27,540 --> 00:00:28,950
the science fiction genre

11
00:00:28,950 --> 00:00:32,340
that is sort of set in
the Industrial Revolution.

12
00:00:32,340 --> 00:00:34,417

And she's the author of
the book by that title,

13
00:00:34,417 --> 00:00:37,980
"Quantum Steampunk: The Physics
of Yesterday's Tomorrow."

14
00:00:37,980 --> 00:00:39,930
- I always really love
talking to physicists

15
00:00:39,930 --> 00:00:43,050
who work at the intersection
of different fields,

16
00:00:43,050 --> 00:00:45,120
so it was really fun to talk to Nicole

17
00:00:45,120 --> 00:00:46,860
and get to hear about her work

18
00:00:46,860 --> 00:00:48,870
at the intersection of quantum physics,

19
00:00:48,870 --> 00:00:51,570
information science, and thermodynamics.

20
00:00:51,570 --> 00:00:53,940
Nicole joined us for this recording

21
00:00:53,940 --> 00:00:56,610
when she was visiting Perimeter
Institute for a conference,

22
00:00:56,610 --> 00:00:59,670
but she also shared about
her times at Perimeter back

23
00:00:59,670 --> 00:01:01,080

when she was a student within

24
00:01:01,080 --> 00:01:04,260
the Perimeter Scholars
International master's program,

25
00:01:04,260 --> 00:01:07,530
which I also work in as a
teaching faculty member.

26
00:01:07,530 --> 00:01:08,880
- So without further ado,

27
00:01:08,880 --> 00:01:11,310
let's dive into the world
of "Quantum Steampunk"

28
00:01:11,310 --> 00:01:12,561
with Nicole Yunger Halpern.

29
00:01:12,561 --> 00:01:15,120
(upbeat music)

30
00:01:15,120 --> 00:01:16,890
Nicole, thank you so much for being here,

31
00:01:16,890 --> 00:01:19,620
and welcome back to Perimeter Institute.

32
00:01:19,620 --> 00:01:21,210
- Thank you. It's really
a pleasure to be here.

33
00:01:21,210 --> 00:01:23,010
Thanks for having me on the podcast.

34
00:01:23,010 --> 00:01:24,907
- I've just finished reading your book,

35
00:01:24,907 --> 00:01:28,260
"Quantum Steampunk: The Physics
of Yesterday's Tomorrow,"

36
00:01:28,260 --> 00:01:29,790
and we're so keen to talk to you about it

37
00:01:29,790 --> 00:01:31,980
because the ideas of quantum

38
00:01:31,980 --> 00:01:35,820
and steampunk I've never heard
combined this way before.

39
00:01:35,820 --> 00:01:38,070
And I honestly have never read a book

40
00:01:38,070 --> 00:01:39,540
about thermodynamics before,

41
00:01:39,540 --> 00:01:41,280
certainly not quantum thermodynamics.

42
00:01:41,280 --> 00:01:43,200
So I'm hoping you can take our audience

43
00:01:43,200 --> 00:01:45,210
on a little bit of a backward journey.

44
00:01:45,210 --> 00:01:47,667
And what's meant by the
term "thermodynamics,"

45
00:01:48,780 --> 00:01:51,753
and is it as scary as I
always thought it was?

46
00:01:52,753 --> 00:01:54,360

- I would say it's not as scary.

47
00:01:54,360 --> 00:01:57,240
The thermodynamics is
simply the study of energy,

48
00:01:57,240 --> 00:01:59,190
the different forms that energy can be in

49
00:01:59,190 --> 00:02:01,950
and the possible transformations
amongst those forms.

50
00:02:01,950 --> 00:02:05,130
The theory of thermodynamics
was developed during the 1800s.

51
00:02:05,130 --> 00:02:07,860
It was inspired by the
Industrial Revolution.

52
00:02:07,860 --> 00:02:09,150
For the first time,

53
00:02:09,150 --> 00:02:13,350
steam engines were being used
on a large scale in industry,

54
00:02:13,350 --> 00:02:14,880
and people wanted to figure out

55
00:02:14,880 --> 00:02:16,770
how efficiently they could operate.

56
00:02:16,770 --> 00:02:19,980
So they gave thermodynamics
this practical bent,

57
00:02:19,980 --> 00:02:22,290

thinking about powering factories

58
00:02:22,290 --> 00:02:24,780
and cooling systems down,

59
00:02:24,780 --> 00:02:28,110
and nowadays, also charging batteries.

60
00:02:28,110 --> 00:02:31,110
So thermodynamics has
this practical viewpoint,

61
00:02:31,110 --> 00:02:33,600
but it's also become very foundational.

62
00:02:33,600 --> 00:02:36,210
This is a side of it that I really love.

63
00:02:36,210 --> 00:02:38,520
In thermodynamics, we end up thinking

64
00:02:38,520 --> 00:02:41,220
about questions like why time flows

65
00:02:41,220 --> 00:02:42,660
in only one direction.

66
00:02:42,660 --> 00:02:46,530
And the thermodynamicists
of the late 1800s also got

67
00:02:46,530 --> 00:02:50,070
to wrestle with fundamental
questions about atomism.

68
00:02:50,070 --> 00:02:53,340
So the theory of atoms hadn't
been entirely well accepted

69
00:02:53,340 --> 00:02:55,170
by the Victorian era.

70
00:02:55,170 --> 00:02:57,090
So people were debating about

71
00:02:57,090 --> 00:03:00,030
to what extent its useful

72
00:03:00,030 --> 00:03:02,550
or scientific to talk about tiny particles

73
00:03:02,550 --> 00:03:04,440
that no one can even see.

74
00:03:04,440 --> 00:03:07,110
Thermodynamics appeals to me in part

75
00:03:07,110 --> 00:03:11,550
because of this fundamental
spirit that it has.

76
00:03:11,550 --> 00:03:13,380
And as you mentioned,

77
00:03:13,380 --> 00:03:17,220
I also see its modern incarnation,
quantum thermodynamics,

78
00:03:17,220 --> 00:03:21,420
as sharing its aesthetic with steampunk.

79
00:03:21,420 --> 00:03:24,900
Steampunk is a genre of
literature, art, and film.

80
00:03:24,900 --> 00:03:28,620
Steampunk stories take place

during the Victorian era.

81
00:03:28,620 --> 00:03:31,800
There are settings such as greedy,

82
00:03:31,800 --> 00:03:34,230
nighttime, dangerous London Streets,

83
00:03:34,230 --> 00:03:38,220
Sherlock Holmes in London, Meiji Japan,

84
00:03:38,220 --> 00:03:39,870
and the Wild wild West.

85
00:03:39,870 --> 00:03:43,920
In these settings are
futuristic technologies,

86
00:03:43,920 --> 00:03:48,920
such as time machines, the
dirigibles, and at automata.

87
00:03:49,410 --> 00:03:52,890
There's this beautiful
blend of old and new

88
00:03:52,890 --> 00:03:55,470
that creates both a sense of nostalgia

89
00:03:55,470 --> 00:04:00,420
and a sense of adventure
and exploration and romance.

90
00:04:00,420 --> 00:04:03,540
In my field, which is at the intersection

91
00:04:03,540 --> 00:04:06,960
of quantum information and thermodynamics,

92
00:04:06,960 --> 00:04:10,380
we're taking the theory of
thermodynamics from the 1800s,

93
00:04:10,380 --> 00:04:13,110
which was built for
large, classical systems,

94
00:04:13,110 --> 00:04:14,218
such as steam engines.
- Like steam engines.

95
00:04:14,218 --> 00:04:15,246
That is quite right.
- Exactly.

96
00:04:15,246 --> 00:04:17,130
- I always think of the
Industrial Revolution

97
00:04:17,130 --> 00:04:19,380
and thermodynamics, I
think of steam trains.

98
00:04:19,380 --> 00:04:20,280
- Exactly.

99
00:04:20,280 --> 00:04:23,700
Nowadays, experimentalists
have great control

100
00:04:23,700 --> 00:04:25,440
over quantum systems,

101
00:04:25,440 --> 00:04:27,390
and the cutting edge technology of the day

102
00:04:27,390 --> 00:04:29,910
is not so much the steam engine,

103
00:04:29,910 --> 00:04:33,120
but cutting edge technologies
include quantum devices,

104
00:04:33,120 --> 00:04:36,840
such as quantum computers
and quantum sensors.

105
00:04:36,840 --> 00:04:39,630
But we need to take this
theory of thermodynamics

106
00:04:39,630 --> 00:04:42,600
from the 1800s and extend it

107
00:04:42,600 --> 00:04:46,050
and really re-envision
it for the 21st century.

108
00:04:46,050 --> 00:04:47,010
In the first place,

109
00:04:47,010 --> 00:04:49,620
how do the thermodynamic laws still hold

110
00:04:49,620 --> 00:04:50,580
for quantum systems?

111
00:04:50,580 --> 00:04:53,610
How can we reformulate
them for quantum systems

112
00:04:53,610 --> 00:04:55,320
and how they encode and interplay

113
00:04:55,320 --> 00:04:57,720
between energy and information,

114
00:04:57,720 --> 00:04:59,640
especially quantum information?

115
00:04:59,640 --> 00:05:03,540
Also, we know from the
quantum information revolution

116
00:05:03,540 --> 00:05:06,300
that quantum phenomena,
such as entanglements,

117
00:05:06,300 --> 00:05:09,810
can enhance information processing tasks,

118
00:05:09,810 --> 00:05:12,120
such as certain computations.

119
00:05:12,120 --> 00:05:14,700
Just as there are
information processing tasks,

120
00:05:14,700 --> 00:05:16,500
there are thermodynamic tasks,

121
00:05:16,500 --> 00:05:19,911
such as charging batteries
and powering cars.

122
00:05:19,911 --> 00:05:22,290
So given that quantum phenomena

123
00:05:22,290 --> 00:05:25,230
can enhance information processing tasks,

124
00:05:25,230 --> 00:05:27,450
can they enhance thermodynamic tasks?

125
00:05:27,450 --> 00:05:29,247

In this intersection
of quantum information

126
00:05:29,247 --> 00:05:31,800
and thermodynamics, we
have, on the one hand,

127
00:05:31,800 --> 00:05:34,620
the thermodynamic theory
of the Victorian era,

128
00:05:34,620 --> 00:05:36,600
and on the other hand,

129
00:05:36,600 --> 00:05:39,000
the futuristic technologies
of quantum computing

130
00:05:39,000 --> 00:05:41,790
and the cutting edge science
of quantum information theory.

131
00:05:41,790 --> 00:05:44,400
I see this fusion of old and new

132
00:05:44,400 --> 00:05:46,983
as sharing its aesthetic with steampunk.

133
00:05:47,910 --> 00:05:50,490
- When I think of quantum thermodynamics,

134
00:05:50,490 --> 00:05:52,380
the very first simple image

135
00:05:52,380 --> 00:05:55,320
that popped into my head was a
very, very small steam train.

136
00:05:55,320 --> 00:05:56,670

And I know that's not right.

137
00:05:56,670 --> 00:05:59,220
Can you tell us what's meant more broadly

138
00:05:59,220 --> 00:06:00,240
by the term "quantum?"

139
00:06:00,240 --> 00:06:01,530
What does quantum describe,

140
00:06:01,530 --> 00:06:04,140
and how does it connect to thermodynamics?

141
00:06:04,140 --> 00:06:05,790
- I think of quantum physics

142
00:06:05,790 --> 00:06:08,820
as very loosely being
the physics of the small.

143
00:06:08,820 --> 00:06:11,850
What we mean by small
can depend on context.

144
00:06:11,850 --> 00:06:13,710
If you have a lot of particles

145
00:06:13,710 --> 00:06:16,080
that are crammed into space small enough

146
00:06:16,080 --> 00:06:17,850
that they interact very strongly,

147
00:06:17,850 --> 00:06:20,730
then that space might be
as large as New York City.

148

00:06:20,730 --> 00:06:22,710
In which case, the particles

149
00:06:22,710 --> 00:06:25,470
that are crammed very closely
together form a black hole.

150
00:06:25,470 --> 00:06:27,090
Quantum physics is
relevant to black holes,

151
00:06:27,090 --> 00:06:28,980
even though black holes seem large

152
00:06:28,980 --> 00:06:31,140
in the sense that New
York City seems large.

153
00:06:31,140 --> 00:06:33,990
But the particles are
crammed so close together

154
00:06:33,990 --> 00:06:35,790
that they interact very strongly,

155
00:06:35,790 --> 00:06:38,010
so we can't describe them

156
00:06:38,010 --> 00:06:41,820
with just the physics
from before the 1920s.

157
00:06:41,820 --> 00:06:43,320
That's how I think of quantum.

158
00:06:43,320 --> 00:06:47,580
You also mentioned the possibility
of quantum steam trains.

159

00:06:47,580 --> 00:06:50,100
Quantum engines have been developed.

160
00:06:50,100 --> 00:06:51,810
They've been designed by theorists

161
00:06:51,810 --> 00:06:54,450
and now realized experimentally.

162
00:06:54,450 --> 00:06:57,000
It turns out that quantum engine can be

163
00:06:57,000 --> 00:06:58,740
as small as a single atom.

164
00:06:58,740 --> 00:07:01,500
That was the basis for
the first quantum engine

165
00:07:01,500 --> 00:07:04,110
that was proposed in 1959,

166
00:07:04,110 --> 00:07:07,170
and then in more detail in 1967.

167
00:07:07,170 --> 00:07:08,610
- So I have to tell you, Nicole,

168
00:07:08,610 --> 00:07:11,280
I actually have some cousins
who listen to this show,

169
00:07:11,280 --> 00:07:14,280
and they work as mechanics for aircraft

170
00:07:14,280 --> 00:07:15,480
and specialized vehicles.

171

00:07:15,480 --> 00:07:18,450
And I was particularly
excited to talk to you today

172
00:07:18,450 --> 00:07:20,610
because I think that you could allow me

173
00:07:20,610 --> 00:07:22,830
to learn a bit more about
something that they do.

174
00:07:22,830 --> 00:07:26,013
So can you actually tell us
really what an engine is?

175
00:07:26,940 --> 00:07:28,590
- We could focus on a heat engine

176
00:07:28,590 --> 00:07:31,770
since that's a simple
and canonical example.

177
00:07:31,770 --> 00:07:36,030
And in particular, a heat
engine that's some device

178
00:07:36,030 --> 00:07:38,640
that has access to two
different environments

179
00:07:38,640 --> 00:07:41,070
at two different temperatures.

180
00:07:41,070 --> 00:07:45,690
Heat naturally flows from
hot systems to cold systems.

181
00:07:45,690 --> 00:07:47,550
And an engine is a device

182
00:07:47,550 --> 00:07:50,580
that takes some of this
heat that is flowing

183
00:07:50,580 --> 00:07:52,410
and turns it into work.

184
00:07:52,410 --> 00:07:54,270
Heats and work are the two different types

185
00:07:54,270 --> 00:07:57,750
of energy that can be
transmitted between objects.

186
00:07:57,750 --> 00:08:01,830
Heat is random energy. It's uncoordinated.

187
00:08:01,830 --> 00:08:04,713
It's the energy of particles
jiggling all about.

188
00:08:05,580 --> 00:08:09,600
Work is organized, coordinated energy

189
00:08:09,600 --> 00:08:10,890
that can be directly harnessed

190
00:08:10,890 --> 00:08:14,730
to do something useful
like push a rock up a hill.

191
00:08:14,730 --> 00:08:19,140
So a heat engine uses this
difference between temperatures

192
00:08:19,140 --> 00:08:20,850
and takes the random heats

193

00:08:20,850 --> 00:08:23,340
and transforms it into useful work

194
00:08:23,340 --> 00:08:26,313
while not changing itself very much.

195
00:08:27,210 --> 00:08:30,510
- And what is the quantum version of that,

196
00:08:30,510 --> 00:08:32,463
the relationship between heat and work?

197
00:08:33,420 --> 00:08:34,650
- What is quantum heat

198
00:08:34,650 --> 00:08:39,330
and what is quantum work
are some of the fundamental

199
00:08:39,330 --> 00:08:43,650
and trickiest questions
of quantum thermodynamics.

200
00:08:43,650 --> 00:08:47,130
I gave some intuition about what heats

201
00:08:47,130 --> 00:08:50,070
and work are in classical thermodynamics.

202
00:08:50,070 --> 00:08:51,660
We can take those intuitions

203
00:08:51,660 --> 00:08:54,120
and try to apply them to quantum systems,

204
00:08:54,120 --> 00:08:58,590
but here's a simple
example of why defining

205
00:08:58,590 --> 00:09:02,190
or conceiving of quantum
heat and work is tricky.

206
00:09:02,190 --> 00:09:03,870
Suppose that we want to measure

207
00:09:03,870 --> 00:09:07,320
how much heat a system absorbs.

208
00:09:07,320 --> 00:09:09,150
We can measure its energy,

209
00:09:09,150 --> 00:09:11,460
then let the system absorb the heats,

210
00:09:11,460 --> 00:09:12,960
and then measure the energy again.

211
00:09:12,960 --> 00:09:15,090
The amount of energy it has

212
00:09:15,090 --> 00:09:17,310
at the end minus the amount of energy

213
00:09:17,310 --> 00:09:19,830
that it has at the beginning
is the heat absorbed.

214
00:09:19,830 --> 00:09:24,060
But suppose that we try this
process on a quantum system.

215
00:09:24,060 --> 00:09:26,340
If we measure a quantum
system, we disturb it.

216
00:09:26,340 --> 00:09:28,740

And if we measure a
quantum system's energy,

217
00:09:28,740 --> 00:09:30,960
we actually change its energy.

218
00:09:30,960 --> 00:09:32,790
So by trying to measure the heat

219
00:09:32,790 --> 00:09:34,770
or work absorbed by a quantum system,

220
00:09:34,770 --> 00:09:36,960
we can change the amount of heat

221
00:09:36,960 --> 00:09:38,487
or work absorbed by the system.

222
00:09:38,487 --> 00:09:40,500
- And that doesn't happen
in the classical sense.

223
00:09:40,500 --> 00:09:42,660
That's only when you're
dealing with quantum particles.

224
00:09:42,660 --> 00:09:43,560
- Right.

225
00:09:43,560 --> 00:09:46,020
So we have to think about quantum work

226
00:09:46,020 --> 00:09:47,520
and heat totally differently.

227
00:09:47,520 --> 00:09:50,430
There's a whole spread

228

00:09:50,430 --> 00:09:52,530
of different definitions of quantum heat

229
00:09:52,530 --> 00:09:55,050
and quantum work that
different people have proposed.

230
00:09:55,050 --> 00:09:56,850
I think of it as a menagerie.

231
00:09:56,850 --> 00:09:58,680
So every time I find a new paper

232
00:09:58,680 --> 00:10:01,110
with a new definition of
quantum heat and work,

233
00:10:01,110 --> 00:10:04,740
I add it to this file
that I call menagerie

234
00:10:04,740 --> 00:10:06,600
of quantum heat and work.

235
00:10:06,600 --> 00:10:08,010
I think of the definitions

236
00:10:08,010 --> 00:10:10,650
as different species in the menagerie.

237
00:10:10,650 --> 00:10:13,830
I think that different
definitions of quantum heat

238
00:10:13,830 --> 00:10:16,470
and work are useful in different contexts.

239
00:10:16,470 --> 00:10:19,710
There is a very well-known trend

240
00:10:19,710 --> 00:10:22,230
in theoretical physics to unify,

241
00:10:22,230 --> 00:10:24,240
to put different definitions

242
00:10:24,240 --> 00:10:26,100
and theories and ideas together

243
00:10:26,100 --> 00:10:28,980
to make some one unified theory,

244
00:10:28,980 --> 00:10:30,630
especially at the Perimeter Institute.

245
00:10:30,630 --> 00:10:32,700
However, I think that

246
00:10:32,700 --> 00:10:36,360
in this very operational
theory of thermodynamics,

247
00:10:36,360 --> 00:10:38,370
where we're really thinking about agents

248
00:10:38,370 --> 00:10:39,870
who are given some resources,

249
00:10:39,870 --> 00:10:41,820
like environments at
different temperatures,

250
00:10:41,820 --> 00:10:46,500
they're trying to perform tasks
like a refrigerator system,

251
00:10:46,500 --> 00:10:48,510

it can be useful to define heat

252
00:10:48,510 --> 00:10:51,960
and work in terms of what
sort of a system we have

253
00:10:51,960 --> 00:10:54,240
and, in particular, what we can do to it.

254
00:10:54,240 --> 00:10:56,190
How we can perform work on it,

255
00:10:56,190 --> 00:10:58,260
how we can poke it, how we can measure it.

256
00:10:58,260 --> 00:11:00,360
What systems we have
around, like batteries,

257
00:11:00,360 --> 00:11:02,100
that they can interact with.

258
00:11:02,100 --> 00:11:04,770
- I love that in your book
you provide some really sort

259
00:11:04,770 --> 00:11:06,030
of straightforward examples,

260
00:11:06,030 --> 00:11:07,920
including beautiful illustrations,

261
00:11:07,920 --> 00:11:09,060
which I want to talk about too.

262
00:11:09,060 --> 00:11:13,080
But the examples, a lot of them
involve a particle in a box.

263
00:11:13,080 --> 00:11:13,913
And it's so simple.

264
00:11:13,913 --> 00:11:15,900
I'd never thought of thermodynamics

265
00:11:15,900 --> 00:11:17,790
as being something that you could explain

266
00:11:17,790 --> 00:11:19,020
with particles in boxes.

267
00:11:19,020 --> 00:11:20,820
Can you tell us why that's such a sort

268
00:11:20,820 --> 00:11:25,023
of standard explanation that
you go back to frequently?

269
00:11:25,890 --> 00:11:27,240
- We very often think

270
00:11:27,240 --> 00:11:32,240
in thermodynamics about gas in a box.

271
00:11:32,370 --> 00:11:35,040
It's quite possible that
many listeners learned

272
00:11:35,040 --> 00:11:37,500
in chemistry class in high school

273
00:11:37,500 --> 00:11:41,730
about ideal gases, their idealizations.

274
00:11:41,730 --> 00:11:43,290
They have very simple properties,

275
00:11:43,290 --> 00:11:44,130
though they're described

276
00:11:44,130 --> 00:11:47,250
by pretty simple equations, in many cases,

277
00:11:47,250 --> 00:11:51,420
but they exhibit really
interesting phenomena,

278
00:11:51,420 --> 00:11:53,610
such as they provide great examples

279
00:11:53,610 --> 00:11:55,170
of the second law of thermodynamics,

280
00:11:55,170 --> 00:11:58,740
which explains or helps us
understand why time flows.

281
00:11:58,740 --> 00:12:01,710
They have properties like volume

282
00:12:01,710 --> 00:12:03,270
and pressure that are measurable.

283
00:12:03,270 --> 00:12:06,300
And by thinking about how
the particles are acting on,

284
00:12:06,300 --> 00:12:07,500
say, the walls of their boxes,

285
00:12:07,500 --> 00:12:09,570
beating against the boxes' walls.

286
00:12:09,570 --> 00:12:11,490
We can think of what pressure even means.

287
00:12:11,490 --> 00:12:13,230
This is a great playground

288
00:12:13,230 --> 00:12:16,290
for understanding thermodynamic
quantities like pressure

289
00:12:16,290 --> 00:12:18,450
and volume and entropy.

290
00:12:18,450 --> 00:12:20,610
Also, in quantum theory
we like thinking a lot

291
00:12:20,610 --> 00:12:22,290
about particles in boxes.

292
00:12:22,290 --> 00:12:25,080
Very often we think about
single particles in boxes.

293
00:12:25,080 --> 00:12:27,060
So in the book, there are some examples

294
00:12:27,060 --> 00:12:31,800
of really, really even
more idealized simple gases

295
00:12:31,800 --> 00:12:34,410
that consist even of single particles.

296
00:12:34,410 --> 00:12:38,190
- And can you take us
back to how you combined

297
00:12:38,190 --> 00:12:41,490
or blended these ideas of thermodynamics

298
00:12:41,490 --> 00:12:43,260
and quantum mechanics and steampunk?

299
00:12:43,260 --> 00:12:44,880
Like, where did that come from?

300
00:12:44,880 --> 00:12:46,650
How did you make those connections?

301
00:12:46,650 --> 00:12:48,180
- That's a good question.

302
00:12:48,180 --> 00:12:53,070
I encountered some steampunk
works as I was growing up.

303
00:12:53,070 --> 00:12:56,250
For instance, I loved the book series

304
00:12:56,250 --> 00:12:59,370
the "Chronicles of Chrestomanci"
by Diana Wynne Jones.

305
00:12:59,370 --> 00:13:04,370
She was a wonderful and
award-winning fiction writer,

306
00:13:04,470 --> 00:13:06,510
one of the best science
fiction fantasy writers

307
00:13:06,510 --> 00:13:08,460
of the 20th century, not
just according to me,

308
00:13:08,460 --> 00:13:10,860
but also authors that
listeners might know,

309
00:13:10,860 --> 00:13:12,510
like Neil Gaiman.

310
00:13:12,510 --> 00:13:16,440
I encountered her works
and Philip Pullman's works.

311
00:13:16,440 --> 00:13:19,170
I didn't realize, though,
that steampunk was a genre.

312
00:13:19,170 --> 00:13:22,140
I didn't quite recognize what
it was that I was reading.

313
00:13:22,140 --> 00:13:25,140
I didn't recognize that
there was some unifying idea

314
00:13:25,140 --> 00:13:26,970
across these works.

315
00:13:26,970 --> 00:13:28,860
Then, at the beginning of grad school,

316
00:13:28,860 --> 00:13:32,070
somehow I discovered that
steampunk was a genre.

317
00:13:32,070 --> 00:13:35,400
By then, I had come to this intersection

318
00:13:35,400 --> 00:13:38,040
of quantum information and thermodynamics,

319
00:13:38,040 --> 00:13:41,850
and I suddenly just realized
that it has the aesthetic

320
00:13:41,850 --> 00:13:43,650
and the spirit of steampunk.

321
00:13:43,650 --> 00:13:48,540
I was so delighted to find
this shared connection

322
00:13:48,540 --> 00:13:51,780
between the hardcore
physics that I was doing

323
00:13:51,780 --> 00:13:53,730
and the genre of
literature, art, and film.

324
00:13:53,730 --> 00:13:55,710
I wrote a blog post about it right

325
00:13:55,710 --> 00:13:57,360
at the beginning of my PhD.

326
00:13:57,360 --> 00:14:00,210
I blogged for Caltech's Quantum Institute.

327
00:14:00,210 --> 00:14:01,980
Then the idea started developing.

328
00:14:01,980 --> 00:14:05,460
It ended up the title of my PhD thesis,

329
00:14:05,460 --> 00:14:09,030
and then the name of my
research group in Maryland,

330
00:14:09,030 --> 00:14:11,310
and then I wrote a book.

331
00:14:11,310 --> 00:14:12,450

- You mentioned grad school.

332
00:14:12,450 --> 00:14:14,460
That was here at Perimeter, right?

333
00:14:14,460 --> 00:14:15,990
- I earned my master's

334
00:14:15,990 --> 00:14:18,630
at the Perimeter Scholars
International Program.

335
00:14:18,630 --> 00:14:20,697
Then I was at Caltech for my PhD.

336
00:14:20,697 --> 00:14:22,440
- And I remember reading, I believe,

337
00:14:22,440 --> 00:14:24,810
in the book that it was at
the Waterloo Public Library,

338
00:14:24,810 --> 00:14:26,010
which is just across the street,

339
00:14:26,010 --> 00:14:28,470
that you came across a book
that had steampunk elements.

340
00:14:28,470 --> 00:14:30,480
Can you tell us what you found

341
00:14:30,480 --> 00:14:31,980
in that book that inspired you?

342
00:14:31,980 --> 00:14:34,890
- During most of my year in PSI,

343

00:14:34,890 --> 00:14:36,750
Perimeter Scholars International,

344
00:14:36,750 --> 00:14:41,730
I was in the Perimeter library working

345
00:14:41,730 --> 00:14:43,410
something like 12 hours a day.

346
00:14:43,410 --> 00:14:46,440
So I didn't have time to go to
the Waterloo Public Library.

347
00:14:46,440 --> 00:14:48,690
But in the spring, classes ended,

348
00:14:48,690 --> 00:14:51,030
and so I finally had a few free hours.

349
00:14:51,030 --> 00:14:53,400
And I explored the
Waterloo Public Library.

350
00:14:53,400 --> 00:14:56,947
I found a novel by the Canadian
poet Jay Ruzesky called

351
00:14:56,947 --> 00:14:58,560
"The Wolsenburg Clock."

352
00:14:58,560 --> 00:15:03,560
It is about an old, old clock in Austria.

353
00:15:04,890 --> 00:15:07,950
The author constructs this story showing

354
00:15:07,950 --> 00:15:12,150
how the clock is affected by

355
00:15:12,150 --> 00:15:14,250
and affects different people

356
00:15:14,250 --> 00:15:17,010
in this town throughout the centuries.

357
00:15:17,010 --> 00:15:20,760
One of the scenes takes
place during the 1800s.

358
00:15:20,760 --> 00:15:24,000
An inventor is about to clean up the clock

359
00:15:24,000 --> 00:15:26,940
and redesign it

360
00:15:26,940 --> 00:15:30,240
and really invest it with
the spirit of what he does,

361
00:15:30,240 --> 00:15:31,580
which is build automata.

362
00:15:31,580 --> 00:15:34,140
So there's a scene in which he is standing

363
00:15:34,140 --> 00:15:36,990
on a balcony gazing down at a ballroom

364
00:15:36,990 --> 00:15:38,700
that he's converted into his workshop.

365
00:15:38,700 --> 00:15:40,410
His children and wife

366
00:15:40,410 --> 00:15:44,670
and so on are building
clockwork-driven elephants

367
00:15:44,670 --> 00:15:47,580
and snakes and snake charmers.

368
00:15:47,580 --> 00:15:51,150
And he has this coat on
that billows out behind him.

369
00:15:51,150 --> 00:15:52,121
- He sounds very steampunk.

370
00:15:52,121 --> 00:15:56,400
- Exactly. That scene stuck in my mind.

371
00:15:56,400 --> 00:15:57,810
And shortly thereafter,

372
00:15:57,810 --> 00:16:01,110
I realized that that scene was steampunk.

373
00:16:01,110 --> 00:16:02,100
And shortly after that,

374
00:16:02,100 --> 00:16:04,200
I realized that my research was too.

375
00:16:04,200 --> 00:16:05,520
- So did you always know

376
00:16:05,520 --> 00:16:07,290
from the time you started your PhD

377
00:16:07,290 --> 00:16:10,200
that that's what you wanted
to focus your thesis on?

378
00:16:10,200 --> 00:16:11,033
- Yes.

379
00:16:11,033 --> 00:16:14,010
During the end of my undergrad years,

380
00:16:14,010 --> 00:16:16,440
I increasingly found my way

381
00:16:16,440 --> 00:16:19,140
to quantum information theory,

382
00:16:19,140 --> 00:16:24,140
and I asked professors
in my physics department

383
00:16:24,300 --> 00:16:26,340
who does the kind of
quantum information theory

384
00:16:26,340 --> 00:16:27,630
that I'm interested in.

385
00:16:27,630 --> 00:16:31,020
It was an abstract mathematical flavor.

386
00:16:31,020 --> 00:16:34,500
They pointed me to some webpages

387
00:16:34,500 --> 00:16:37,110
of some faculty members across the world.

388
00:16:37,110 --> 00:16:40,380
I increasingly honed in on phrases

389
00:16:40,380 --> 00:16:44,370
and ideas that really spoke to me.

390
00:16:44,370 --> 00:16:45,930
I found that they were

at this intersection

391
00:16:45,930 --> 00:16:48,420
of quantum information
theory and thermodynamics,

392
00:16:48,420 --> 00:16:51,510
where people are thinking
about uncertainty

393
00:16:51,510 --> 00:16:53,460
and entropies and information

394
00:16:53,460 --> 00:16:55,560
and energy in a fundamental way.

395
00:16:55,560 --> 00:16:58,530
Shortly thereafter, I came to Perimeter.

396
00:16:58,530 --> 00:17:00,900
I had the wonderful good fortune

397
00:17:00,900 --> 00:17:03,570
to work for my final project

398
00:17:03,570 --> 00:17:06,270
with someone who was a
postdoc here at the time,

399
00:17:06,270 --> 00:17:08,610
Markus Muller, and Robert Spekkens,

400
00:17:08,610 --> 00:17:10,380
who's a faculty member here.

401
00:17:10,380 --> 00:17:13,620
We worked on a topic
in quantum information,

402
00:17:13,620 --> 00:17:15,690
theoretic thermodynamics.

403
00:17:15,690 --> 00:17:17,227
At the end of the project,
we said to each other,

404
00:17:17,227 --> 00:17:20,040
"Okay, so now we've gained this toolkit.

405
00:17:20,040 --> 00:17:21,630
What shall we do with it?"

406
00:17:21,630 --> 00:17:23,610
I came up with a project,

407
00:17:23,610 --> 00:17:26,190
and that was the first project in my PhD.

408
00:17:26,190 --> 00:17:28,050
There was always another project

409
00:17:28,050 --> 00:17:30,810
and more collaborators to reach out to.

410
00:17:30,810 --> 00:17:33,720
- Since we're asking you
about your PhD right now,

411
00:17:33,720 --> 00:17:34,860
as part of this show,

412
00:17:34,860 --> 00:17:37,470
we collect questions from
some of our listeners.

413
00:17:37,470 --> 00:17:41,280
And a current PSI student

here named Anna Knorr sent

414
00:17:41,280 --> 00:17:43,233
in a question about your thesis.

415
00:17:45,000 --> 00:17:49,380
- In your thesis, you
write, "Steampunks dream it,

416
00:17:49,380 --> 00:17:52,740
Quantum information
thermodynamicists live it."

417
00:17:52,740 --> 00:17:54,840
Is that simply a cool slogan,

418
00:17:54,840 --> 00:17:57,270
or does it truly motivate you

419
00:17:57,270 --> 00:17:59,253
and drive you in your research?

420
00:18:00,570 --> 00:18:05,570
- Steampunk is a genre of
science fiction and fantasy.

421
00:18:05,760 --> 00:18:09,180
It is seen as something that isn't true.

422
00:18:09,180 --> 00:18:12,510
However, I do believe that it is coming

423
00:18:12,510 --> 00:18:15,060
to life in the intersection

424
00:18:15,060 --> 00:18:18,360
of quantum information
theory and thermodynamics.

425
00:18:18,360 --> 00:18:21,990
Thermodynamics was
developed during the 1800s.

426
00:18:21,990 --> 00:18:25,380
We carry a bit of the
Victorian era with us

427
00:18:25,380 --> 00:18:27,330
when we're doing thermodynamics.

428
00:18:27,330 --> 00:18:30,120
And quantum computers are
futuristic technologies.

429
00:18:30,120 --> 00:18:31,650
We're still building them.

430
00:18:31,650 --> 00:18:34,290
And quantum information theory
is cutting edge science.

431
00:18:34,290 --> 00:18:38,040
So I do believe that quantum
information thermodynamicists

432
00:18:38,040 --> 00:18:41,430
really are living what

433
00:18:41,430 --> 00:18:44,730
until now has been seen
as a fiction, steampunk.

434
00:18:44,730 --> 00:18:46,830
- And in a lot of what
you've been talking about,

435
00:18:46,830 --> 00:18:48,360
you've been saying your work is really

436
00:18:48,360 --> 00:18:50,310
at an intersection of several fields,

437
00:18:50,310 --> 00:18:52,470
one of which is information science.

438
00:18:52,470 --> 00:18:53,700
And I'm wondering if you can talk

439
00:18:53,700 --> 00:18:55,170
a little bit more about information.

440
00:18:55,170 --> 00:18:56,460
I know in your book you say

441
00:18:56,460 --> 00:18:59,100
that we live in an information age.

442
00:18:59,100 --> 00:19:02,220
So can you tell us a little
bit about why you said that

443
00:19:02,220 --> 00:19:05,043
and maybe first just what information is?

444
00:19:06,240 --> 00:19:09,690
- I've heard two
definitions of information.

445
00:19:09,690 --> 00:19:11,190
One that's a bit easier to explain

446
00:19:11,190 --> 00:19:13,950
is information is the ability

447
00:19:13,950 --> 00:19:15,870
to distinguish between alternatives

448
00:19:15,870 --> 00:19:18,180
or a necessary ingredient

449
00:19:18,180 --> 00:19:20,700
for distinguishing between alternatives.

450
00:19:20,700 --> 00:19:23,340
For instance, when you
get up in the morning

451
00:19:23,340 --> 00:19:25,860
and need to figure out what to wear,

452
00:19:25,860 --> 00:19:27,930
you need to know what the weather is like.

453
00:19:27,930 --> 00:19:30,240
So you peer through the window, perhaps,

454
00:19:30,240 --> 00:19:34,410
and see that there's sun or there's rain.

455
00:19:34,410 --> 00:19:35,520
When you've peered through the window,

456
00:19:35,520 --> 00:19:36,930
you've gained information.

457
00:19:36,930 --> 00:19:38,373
You've been surprised.

458
00:19:39,360 --> 00:19:42,540
So information is that
which gives us the ability

459
00:19:42,540 --> 00:19:45,450
to distinguish whether

it's sunny or rainy.

460
00:19:45,450 --> 00:19:48,510
- And is information itself thermodynamic?

461
00:19:48,510 --> 00:19:51,960
Does information have an
energy component to it,

462
00:19:51,960 --> 00:19:56,190
or does quantum information
have an energy component to it?

463
00:19:56,190 --> 00:20:00,060
- Information plays a
role in thermodynamics.

464
00:20:00,060 --> 00:20:02,220
For instance, in my book,

465
00:20:02,220 --> 00:20:04,800
I walk through some examples that show

466
00:20:04,800 --> 00:20:09,800
that we can use information
to turn heats into work.

467
00:20:10,980 --> 00:20:14,820
We said that heat is random,
uncoordinated energy,

468
00:20:14,820 --> 00:20:19,080
and work is coordinated
energy that's directly useful.

469
00:20:19,080 --> 00:20:20,880
If we have information,

470
00:20:20,880 --> 00:20:22,770

then we can run what's sometimes called

471
00:20:22,770 --> 00:20:26,610
an information engine to
take those random heats

472
00:20:26,610 --> 00:20:28,950
and convert it into useful work.

473
00:20:28,950 --> 00:20:33,950
We can also run the engine
backwards and perform work,

474
00:20:34,740 --> 00:20:38,313
such as by draining a
battery, to gain information.

475
00:20:39,330 --> 00:20:40,560
There's certainly an interplay

476
00:20:40,560 --> 00:20:42,360
between information and energy.

477
00:20:42,360 --> 00:20:44,520
- And Nicole, when I first got your book,

478
00:20:44,520 --> 00:20:47,070
the first thing I did was,
of course, to flip through it

479
00:20:47,070 --> 00:20:49,440
and admire the really
beautiful illustrations

480
00:20:49,440 --> 00:20:50,790
that Colin already talked about,

481
00:20:50,790 --> 00:20:52,080
but when I did that,

482
00:20:52,080 --> 00:20:54,780
there was one phrase that jumped out

483
00:20:54,780 --> 00:20:56,430
to me right from the beginning.

484
00:20:56,430 --> 00:21:00,090
And it's on page 19
where you have a section

485
00:21:00,090 --> 00:21:03,510
that's called The Liver
of Information Theory.

486
00:21:03,510 --> 00:21:06,120
Can you tell us a little bit about this?

487
00:21:06,120 --> 00:21:07,680
- Yes.

488
00:21:07,680 --> 00:21:10,170
When I was in high school,

489
00:21:10,170 --> 00:21:13,147
I had a biology teacher who said,

490
00:21:13,147 --> 00:21:15,480
"If you ever don't know the answer

491
00:21:15,480 --> 00:21:18,090
to a question on a test of mine,

492
00:21:18,090 --> 00:21:19,819
you should write down 'liver.'"

493
00:21:19,819 --> 00:21:20,938
(Colin laughs)

494
00:21:20,938 --> 00:21:24,540
The liver turns out to
perform a ridiculous number

495
00:21:24,540 --> 00:21:25,890
of functions in the human body.

496
00:21:25,890 --> 00:21:28,890
So if you don't know the
answer to a biology question

497
00:21:28,890 --> 00:21:30,480
and you answer liver,

498
00:21:30,480 --> 00:21:32,400
then you have an
anomalously high probability

499
00:21:32,400 --> 00:21:33,750
of being correct.

500
00:21:33,750 --> 00:21:38,077
Similarly, in information
theory, if you're asked,

501
00:21:38,077 --> 00:21:40,140
"What is the optimal efficiency

502
00:21:40,140 --> 00:21:43,920
with which we can perform some
information processing task?"

503
00:21:43,920 --> 00:21:47,280
and you answer, "It's
given by an entropy,"

504
00:21:47,280 --> 00:21:50,160
then you have an anomalously

high probability being correct.

505
00:21:50,160 --> 00:21:52,740
So very often in information
theory the answer

506
00:21:52,740 --> 00:21:54,870
to a question is entropy.

507
00:21:54,870 --> 00:21:58,230
So I think of entropy as the
liver of information theory.

508
00:21:58,230 --> 00:21:59,580
I should also mention,

509
00:21:59,580 --> 00:22:02,970
partially in response to
Colin's recent question,

510
00:22:02,970 --> 00:22:07,260
that entropy is a manifestation

511
00:22:07,260 --> 00:22:10,680
of information in thermodynamics.

512
00:22:10,680 --> 00:22:13,470
Entropy is a measure of uncertainty,

513
00:22:13,470 --> 00:22:15,000
how little we know.

514
00:22:15,000 --> 00:22:17,910
And entropy comes up even

515
00:22:17,910 --> 00:22:20,280
in the second law of thermodynamics,

516

00:22:20,280 --> 00:22:22,770
which is a very, very
fundamental statement.

517
00:22:22,770 --> 00:22:25,350
- Yeah, entropy is a
concept you hear a lot

518
00:22:25,350 --> 00:22:27,690
in different branches
of physics and science.

519
00:22:27,690 --> 00:22:29,280
And honestly, it's one

520
00:22:29,280 --> 00:22:31,170
that I have trouble
wrapping my head around.

521
00:22:31,170 --> 00:22:32,940
I hope I'm not alone in that.

522
00:22:32,940 --> 00:22:34,710
Can you give us a bit more of an idea?

523
00:22:34,710 --> 00:22:35,670
What does that mean to say

524
00:22:35,670 --> 00:22:39,000
that entropy sort of plays
a role in information?

525
00:22:39,000 --> 00:22:42,117
- First, there are many
different entropies,

526
00:22:42,117 --> 00:22:45,210
and entropy is a measure of uncertainty.

527

00:22:45,210 --> 00:22:46,860
At least that's how I think of it.

528
00:22:46,860 --> 00:22:50,850
For instance, I recently
lived in the Boston area,

529
00:22:50,850 --> 00:22:52,830
and I came to learn that the weather

530
00:22:52,830 --> 00:22:56,070
in the Boston area is a
very, very random variable.

531
00:22:56,070 --> 00:22:58,620
On any given day, there's some probability

532
00:22:58,620 --> 00:23:00,780
that the weather will be mostly sunny,

533
00:23:00,780 --> 00:23:02,490
some probability that
it'll be mostly rainy,

534
00:23:02,490 --> 00:23:04,320
some probability that
it'll be mostly cloudy,

535
00:23:04,320 --> 00:23:06,900
some probability that
it'll be mostly snowing.

536
00:23:06,900 --> 00:23:11,700
If on any given day you
learn what the weather is,

537
00:23:11,700 --> 00:23:14,280
then you gain some amount of information,

538

00:23:14,280 --> 00:23:16,470
you are surprised by some amount,

539
00:23:16,470 --> 00:23:19,020
and a measure of how surprised you are

540
00:23:19,020 --> 00:23:21,000
is an entropic quantity.

541
00:23:21,000 --> 00:23:24,300
It depends on how probable
that weather pattern was.

542
00:23:24,300 --> 00:23:27,210
Also, suppose that you
perform this process

543
00:23:27,210 --> 00:23:28,440
on many, many days.

544
00:23:28,440 --> 00:23:31,677
On each of many, many days,
you learn what the weather is,

545
00:23:31,677 --> 00:23:35,520
and you average your
uncertainty over many days.

546
00:23:35,520 --> 00:23:37,800
This is another measure of uncertainty.

547
00:23:37,800 --> 00:23:40,020
There are different
measures of uncertainty

548
00:23:40,020 --> 00:23:41,940
that describe different contexts.

549
00:23:41,940 --> 00:23:44,130

So there are different entropies.

550
00:23:44,130 --> 00:23:48,180
I've described entropy in an
information theoretic way.

551
00:23:48,180 --> 00:23:49,740
We can also see how it shows up

552
00:23:49,740 --> 00:23:53,190
in thermodynamics via
your favorite example

553
00:23:53,190 --> 00:23:54,030
of a gas in a box.

554
00:23:54,030 --> 00:23:55,560
- Mm-hmm.

555
00:23:55,560 --> 00:23:58,080
- Suppose that there is some gas in a box.

556
00:23:58,080 --> 00:24:01,260
It has some large-scale properties

557
00:24:01,260 --> 00:24:03,270
that characterize the gas as a whole,

558
00:24:03,270 --> 00:24:07,170
such as the energy of the
gas, the volume of the gas,

559
00:24:07,170 --> 00:24:09,330
the number of particles in the gas.

560
00:24:09,330 --> 00:24:11,070
But we might have just this little bit of,

561

00:24:11,070 --> 00:24:14,340
or, I shouldn't say bits since
that's a technical term here

562
00:24:14,340 --> 00:24:16,650
in information theory context.

563
00:24:16,650 --> 00:24:20,070
Suppose that we just know these
few large-scale properties.

564
00:24:20,070 --> 00:24:23,700
We could also zoom in on the gas particles

565
00:24:23,700 --> 00:24:26,310
and realize that, at any given instant,

566
00:24:26,310 --> 00:24:28,860
the gas particles have some positions,

567
00:24:28,860 --> 00:24:29,870
They have some momenta.

568
00:24:29,870 --> 00:24:31,500
So they have some masses,

569
00:24:31,500 --> 00:24:32,880
and they're moving with certain speeds

570
00:24:32,880 --> 00:24:34,770
in certain directions.

571
00:24:34,770 --> 00:24:38,520
There are many of these
microscopic configurations

572
00:24:38,520 --> 00:24:42,360
that are consistent with
one large-scale picture

573
00:24:42,360 --> 00:24:45,390
of energy and volume and particle number.

574
00:24:45,390 --> 00:24:48,960
If we know just those
large-scale properties,

575
00:24:48,960 --> 00:24:51,510
then how ignorant are we

576
00:24:51,510 --> 00:24:53,730
of the microscopic configuration?

577
00:24:53,730 --> 00:24:55,353
That's a thermodynamic entropy.

578
00:24:56,190 --> 00:24:58,200
- Lauren's last question reminded me

579
00:24:58,200 --> 00:25:00,120
that one of my favorite
parts about your book

580
00:25:00,120 --> 00:25:02,523
is the chapter titles and the subtitles.

581
00:25:04,065 --> 00:25:05,730
They're are some of the most
creative ones I've ever seen,

582
00:25:05,730 --> 00:25:09,450
including How to Insult a
Quantum Information Theorist.

583
00:25:09,450 --> 00:25:10,800
so I'm hoping you can tell us,

584

00:25:10,800 --> 00:25:13,350
how do we insult a quantum
information theorist?

585
00:25:13,350 --> 00:25:16,050
- Say, "Oh, quantum information theory.

586
00:25:16,050 --> 00:25:18,720
Isn't that all just linear algebra?"

587
00:25:18,720 --> 00:25:20,880
- So if I were a quantum
information theorist,

588
00:25:20,880 --> 00:25:22,230
why would I be insulted by that?

589
00:25:22,230 --> 00:25:25,050
- I can explain with a story.

590
00:25:25,050 --> 00:25:26,670
When I was an undergrad,

591
00:25:26,670 --> 00:25:29,340
I took a linear algebra course,

592
00:25:29,340 --> 00:25:32,490
and I was asked to
explain what I was doing.

593
00:25:32,490 --> 00:25:34,950
I said, "I'm learning

594
00:25:34,950 --> 00:25:37,440
to solve basically the
simplest equations."

595
00:25:37,440 --> 00:25:38,940
These are actually the kinds of equations

596
00:25:38,940 --> 00:25:40,590
that we encounter in middle school.

597
00:25:40,590 --> 00:25:42,637
And in response I was told,

598
00:25:42,637 --> 00:25:44,365
"And for this you had to go to college?"

599
00:25:44,365 --> 00:25:45,750
(Colin laughs)

600
00:25:45,750 --> 00:25:49,920
So linear algebra is a somewhat
straightforward extension

601
00:25:49,920 --> 00:25:51,810
of what we learn in middle school.

602
00:25:51,810 --> 00:25:52,650
Except in middle school,

603
00:25:52,650 --> 00:25:54,330
we don't deal with tens

604
00:25:54,330 --> 00:25:56,880
or hundreds of these equations at a time.

605
00:25:56,880 --> 00:25:59,700
- And on the topic of
titles and subtitles,

606
00:25:59,700 --> 00:26:02,100
I don't wanna risk giving
away too many spoilers

607
00:26:02,100 --> 00:26:03,660

because I want people to read your book,

608
00:26:03,660 --> 00:26:06,360
but the subtitle of your entire book

609
00:26:06,360 --> 00:26:08,700
is The Physics of Yesterday's Tomorrow,

610
00:26:08,700 --> 00:26:11,790
and this is also the title
of a chapter in your book.

611
00:26:11,790 --> 00:26:15,330
Can you tell us a little
bit about this title?

612
00:26:15,330 --> 00:26:17,490
- I wish I could take credit for it,

613
00:26:17,490 --> 00:26:20,430
but my acquisitions editor

614
00:26:20,430 --> 00:26:22,500
at Johns Hopkins University Press,

615
00:26:22,500 --> 00:26:23,640
together with her team,

616
00:26:23,640 --> 00:26:25,260
came up with this subtitle.

617
00:26:25,260 --> 00:26:27,930
And as soon as I saw it,
I fell in love with it.

618
00:26:27,930 --> 00:26:29,850
I think of this subtitle

619

00:26:29,850 --> 00:26:33,300
as embodying the idea
of quantum steampunk.

620
00:26:33,300 --> 00:26:36,660
It is a branch of physics,
as well as chemistry,

621
00:26:36,660 --> 00:26:40,380
but it is the physics
of yesterday's tomorrow

622
00:26:40,380 --> 00:26:44,280
in that quantum steampunk re-envisions

623
00:26:44,280 --> 00:26:48,900
the Victorian era's thermodynamics
for the 21st century.

624
00:26:48,900 --> 00:26:52,020
- Because steampunk is
such a visual aesthetic,

625
00:26:52,020 --> 00:26:53,430
you had an illustrator

626
00:26:53,430 --> 00:26:55,950
to create these beautiful
diagrams in the book.

627
00:26:55,950 --> 00:26:58,650
Can you tell us how that
came to be and how...

628
00:26:58,650 --> 00:26:59,550
I assume there's not

629
00:26:59,550 --> 00:27:01,050
that many illustrators out there

630
00:27:01,050 --> 00:27:02,940
who just know quantum thermodynamics

631
00:27:02,940 --> 00:27:04,050
like the back of their hand.

632
00:27:04,050 --> 00:27:06,120
How did that relationship come to be?

633
00:27:06,120 --> 00:27:08,670
- The illustrator is Todd Cahill.

634
00:27:08,670 --> 00:27:10,260
He's a steampunk artist,

635
00:27:10,260 --> 00:27:12,780
and he actually had no experience

636
00:27:12,780 --> 00:27:15,210
with quantum physics whatsoever.

637
00:27:15,210 --> 00:27:17,640
So we had a lot of conversations.

638
00:27:17,640 --> 00:27:22,640
I encountered him through
another steampunk artist.

639
00:27:22,800 --> 00:27:24,030
Couple of years ago,

640
00:27:24,030 --> 00:27:28,170
the steampunk artist Bruce
Rosenbaum reached out to me.

641
00:27:28,170 --> 00:27:31,110
He had watched a talk that I had given.

642
00:27:31,110 --> 00:27:34,380
I actually suspect that it
was the first colloquium

643
00:27:34,380 --> 00:27:36,424
that I gave for the IQC,

644
00:27:36,424 --> 00:27:38,610
the Institute for Quantum
Computing, near Perimeter.

645
00:27:38,610 --> 00:27:41,280
He said, "I love the spirit of this talk.

646
00:27:41,280 --> 00:27:43,320
Would you like to collaborate

647
00:27:43,320 --> 00:27:46,080
on a quantum steampunk sculpture?"

648
00:27:46,080 --> 00:27:50,190
Bruce creates large, as in human size,

649
00:27:50,190 --> 00:27:52,470
or even larger, interactive,

650
00:27:52,470 --> 00:27:54,660
kinetic steampunk sculptures

651
00:27:54,660 --> 00:27:57,930
for museums and restaurants and hotels.

652
00:27:57,930 --> 00:28:01,260
I had no experience with
anything like this ever before,

653
00:28:01,260 --> 00:28:03,120
but it sounded like

fun, so I said, "Sure."

654
00:28:03,120 --> 00:28:05,700
We talked a lot about possible designs.

655
00:28:05,700 --> 00:28:07,830
We ended up collaborating

656
00:28:07,830 --> 00:28:10,380
with another artist to create a design

657
00:28:10,380 --> 00:28:14,190
of a quantum engine
formed from a trapped ion

658
00:28:14,190 --> 00:28:18,150
with the classical counterpart
of the engine on the outside.

659
00:28:18,150 --> 00:28:20,250
The sculpture as a whole looks like

660
00:28:20,250 --> 00:28:25,080
an armillary sphere hearkening
back to a few centuries ago.

661
00:28:25,080 --> 00:28:27,540
But also, this armillary
sphere is a sphere,

662
00:28:27,540 --> 00:28:30,060
so if you show it to someone
in quantum information,

663
00:28:30,060 --> 00:28:32,100
they'll say, "Oh, that looks
like the Bloch sphere,"

664
00:28:32,100 --> 00:28:34,890

which represents the state of a qubit,

665
00:28:34,890 --> 00:28:36,930
a basic unit of quantum information.

666
00:28:36,930 --> 00:28:40,020
After I started collaborating with Bruce,

667
00:28:40,020 --> 00:28:41,460
I wrote this book.

668
00:28:41,460 --> 00:28:44,370
And eventually, we needed
to find an illustrator,

669
00:28:44,370 --> 00:28:48,210
so I asked Bruce if he
could suggest anyone.

670
00:28:48,210 --> 00:28:49,980
And he suggested Todd.

671
00:28:49,980 --> 00:28:54,480
Todd was great about learning
about quantum physics

672
00:28:54,480 --> 00:28:56,400
and going back and forth with me

673
00:28:56,400 --> 00:29:01,400
about representing visually,
in a quite beautiful way,

674
00:29:01,440 --> 00:29:04,920
images that I could only
sketch in a very poor manner

675
00:29:04,920 --> 00:29:06,630
'cause I have very little

training in drawing.

676
00:29:06,630 --> 00:29:08,910
- I was gonna ask if these were images

677
00:29:08,910 --> 00:29:10,170
that you already had in your head,

678
00:29:10,170 --> 00:29:12,803
or if the collaborative process
with him helped you form,

679
00:29:12,803 --> 00:29:16,170
you know, how do you
visualize this stuff that is,

680
00:29:16,170 --> 00:29:17,640
most of it's invisible to us?

681
00:29:17,640 --> 00:29:18,900
It's at the quantum level.

682
00:29:18,900 --> 00:29:19,950
- Yes.

683
00:29:19,950 --> 00:29:22,980
I sketched some diagrams, but again,

684
00:29:22,980 --> 00:29:25,470
I have very, very little
training in drawing.

685
00:29:25,470 --> 00:29:28,117
So I gave him my poor
little sketches and said,

686
00:29:28,117 --> 00:29:29,703
"Can you make these look steampunk?

687
00:29:29,703 --> 00:29:33,060
Then can you add some like
flair here and there?"

688
00:29:33,060 --> 00:29:36,750
And that is what he does extremely well.

689
00:29:36,750 --> 00:29:39,570
So he turned my stick figure type drawings

690
00:29:39,570 --> 00:29:41,760
into beautiful illustrations.

691
00:29:41,760 --> 00:29:43,710
- And some of those illustrations sort

692
00:29:43,710 --> 00:29:46,590
of provide explanation of what's happening

693
00:29:46,590 --> 00:29:48,090
with some characters in your book.

694
00:29:48,090 --> 00:29:49,860
It's a very fascinating book in the sense

695
00:29:49,860 --> 00:29:51,480
that it's a science book kinda

696
00:29:51,480 --> 00:29:54,840
with a steampunk novella woven into it,

697
00:29:54,840 --> 00:29:56,670
with characters, fictional characters.

698
00:29:56,670 --> 00:29:58,350
Can you tell us who those characters are

699

00:29:58,350 --> 00:30:00,720
and where they came from?

700
00:30:00,720 --> 00:30:01,553
- Yes.

701
00:30:01,553 --> 00:30:04,860
So the book is mostly nonfiction,

702
00:30:04,860 --> 00:30:07,770
but each chapter begins
with a little snippet

703
00:30:07,770 --> 00:30:12,120
from a steampunk novel that
resides in my imagination.

704
00:30:12,120 --> 00:30:15,030
There are characters in that story.

705
00:30:15,030 --> 00:30:19,500
The main characters are called
Audrey, Baxter, and Caspian.

706
00:30:19,500 --> 00:30:22,230
They have this nemesis, Ewart.

707
00:30:22,230 --> 00:30:26,430
I enjoyed playing with
the tropes of steampunk

708
00:30:26,430 --> 00:30:29,400
in what is otherwise a very serious novel

709
00:30:29,400 --> 00:30:31,260
about hardcore science.

710
00:30:31,260 --> 00:30:35,850
I tried out this strategy

when writing an article

711
00:30:35,850 --> 00:30:38,880
for Scientific American
a couple of years ago.

712
00:30:38,880 --> 00:30:41,760
I was asked to write an article
about quantum steampunk,

713
00:30:41,760 --> 00:30:43,980
and I thought that it
would be fun to start

714
00:30:43,980 --> 00:30:46,380
with something quite different

715
00:30:46,380 --> 00:30:49,320
from the hardcore science
that quantum steampunk is,

716
00:30:49,320 --> 00:30:52,050
to start with this playful
snippet from an imaginary novel

717
00:30:52,050 --> 00:30:54,450
to illustrate what steampunk is.

718
00:30:54,450 --> 00:30:57,060
So I partially wanted to
illustrate what steampunk is

719
00:30:57,060 --> 00:30:58,830
for those unfamiliar with it.

720
00:30:58,830 --> 00:31:03,510
Partially, I wanted to have
fun playing with these tropes,

721

00:31:03,510 --> 00:31:05,910
like the very spirited,

722
00:31:05,910 --> 00:31:09,090
vivacious, young girl in the Victorian era

723
00:31:09,090 --> 00:31:11,610
who refuses to be pinned down

724
00:31:11,610 --> 00:31:13,530
by the expectations of her society

725
00:31:13,530 --> 00:31:15,630
and corsets and so on and so forth.

726
00:31:15,630 --> 00:31:19,860
Also, dark, dangerous London streets.

727
00:31:19,860 --> 00:31:21,900
It was fun to play with these ideas.

728
00:31:21,900 --> 00:31:23,850
They did end up helpful later on

729
00:31:23,850 --> 00:31:27,630
in the chapters to
illustrate scientific ideas.

730
00:31:27,630 --> 00:31:30,930
Very often in an operational theory,

731
00:31:30,930 --> 00:31:35,400
like information theory, we
speak in terms of agents.

732
00:31:35,400 --> 00:31:37,650
I think of an operational theory

733

00:31:37,650 --> 00:31:41,310
as one that can be
phrased in terms of agents

734
00:31:41,310 --> 00:31:42,870
who have certain resources

735
00:31:42,870 --> 00:31:44,400
and need to perform certain tasks,

736
00:31:44,400 --> 00:31:46,800
so they try to figure out
how to perform those tasks

737
00:31:46,800 --> 00:31:48,300
as efficiently as possible.

738
00:31:48,300 --> 00:31:51,480
Information theory is operational.

739
00:31:51,480 --> 00:31:52,440
In information theory,

740
00:31:52,440 --> 00:31:56,010
we think about the tasks
of compressing data,

741
00:31:56,010 --> 00:32:00,930
communicating information over
a noisy channel, and so on.

742
00:32:00,930 --> 00:32:03,750
In thermodynamics, we
think about refrigerating

743
00:32:03,750 --> 00:32:06,930
and charging batteries and
powering cars and so on.

744

00:32:06,930 --> 00:32:11,930
Many of information theory's
operational stories are phrased

745
00:32:12,120 --> 00:32:15,120
in terms of characters Alice and Bob.

746
00:32:15,120 --> 00:32:16,710
They have a friend, Caspian.

747
00:32:16,710 --> 00:32:20,820
Sometimes they are eavesdropped on by Eve.

748
00:32:20,820 --> 00:32:22,650
So I gave the characters

749
00:32:22,650 --> 00:32:25,470
in this imaginary steampunk novel names

750
00:32:25,470 --> 00:32:27,183
that begin with the same
letters, A, B, C, and E.

751
00:32:27,183 --> 00:32:29,460
- It's funny, I didn't
even put that together

752
00:32:29,460 --> 00:32:30,450
until just now.

753
00:32:30,450 --> 00:32:31,320
We are actually sitting

754
00:32:31,320 --> 00:32:33,930
in the Alice room directly
below the Bob room just

755
00:32:33,930 --> 00:32:37,950
to demonstrate how commonly

used those terms are in science.

756
00:32:37,950 --> 00:32:39,990
- Yes, very relevant.
- Sorry, go on. (chuckles)

757
00:32:39,990 --> 00:32:43,500
- I figured that some readers would see

758
00:32:43,500 --> 00:32:45,390
that very quickly, and other readers,

759
00:32:45,390 --> 00:32:47,520
say, who might come from
the steampunk community,

760
00:32:47,520 --> 00:32:49,920
would maybe not make the connection

761
00:32:49,920 --> 00:32:52,680
between Audrey and Alice,

762
00:32:52,680 --> 00:32:54,390
but instead would recognize more

763
00:32:54,390 --> 00:32:56,580
of the steampunk tropes
and smile at those.

764
00:32:56,580 --> 00:32:59,670
I thought referring to
characters such as Alice

765
00:32:59,670 --> 00:33:02,790
and Bob is really helpful
for explaining our science

766
00:33:02,790 --> 00:33:06,780
and formalizing information theoretic

767
00:33:06,780 --> 00:33:08,520
and thermodynamic tasks.

768
00:33:08,520 --> 00:33:11,130
But we refer to Alice and Bob so much,

769
00:33:11,130 --> 00:33:12,930
it would be fun to have
different characters.

770
00:33:12,930 --> 00:33:15,090
Hence Audrey and Baxter and so on.

771
00:33:15,090 --> 00:33:17,220
- I think this is just
really what makes your book

772
00:33:17,220 --> 00:33:19,260
so unique, is that the steampunk

773
00:33:19,260 --> 00:33:21,450
is really infused all the way throughout.

774
00:33:21,450 --> 00:33:24,270
And we actually got
another question sent in

775
00:33:24,270 --> 00:33:25,470
on a related topic.

776
00:33:25,470 --> 00:33:27,570
This one is from Matt Duschenes,

777
00:33:27,570 --> 00:33:29,550
who's currently a PhD student

778
00:33:29,550 --> 00:33:31,470

at the Institute for Quantum Computing

779
00:33:31,470 --> 00:33:33,063
and the Perimeter Institute.

780
00:33:33,960 --> 00:33:35,100
- So you found a great connection,

781
00:33:35,100 --> 00:33:37,440
and we're really inspired
by the genre of steampunk

782
00:33:37,440 --> 00:33:39,540
to drive your research directions.

783
00:33:39,540 --> 00:33:40,980
Do you think there are
more serious opportunities

784
00:33:40,980 --> 00:33:42,600
for this kind of inspiration,

785
00:33:42,600 --> 00:33:43,980
and that physics as a field should look

786
00:33:43,980 --> 00:33:45,723
to draw more connections with art?

787
00:33:46,560 --> 00:33:47,670
- I think that

788
00:33:47,670 --> 00:33:50,670
how quantum thermodynamics
shares its spirit

789
00:33:50,670 --> 00:33:53,280
with steampunk is kind of a gift.

790

00:33:53,280 --> 00:33:55,440
It makes doing the physics even more fun

791
00:33:55,440 --> 00:33:56,760
because of this connection.

792
00:33:56,760 --> 00:33:58,890
I think that it would be wonderful

793
00:33:58,890 --> 00:34:00,450
to find more such connections

794
00:34:00,450 --> 00:34:05,450
between fields of science and
genres of art and literature.

795
00:34:05,910 --> 00:34:08,250
I've always enjoyed studying everything,

796
00:34:08,250 --> 00:34:11,550
and I was drawn to physics in the manner

797
00:34:11,550 --> 00:34:14,430
of a natural philosopher from,

798
00:34:14,430 --> 00:34:17,700
say, the 1700s or early 1800s.

799
00:34:17,700 --> 00:34:22,440
They studied, in a very rigorous sense,

800
00:34:22,440 --> 00:34:27,440
aesthetics, as well as geometry
and astronomy and so on.

801
00:34:27,630 --> 00:34:29,820
I think that there's a lot of richness

802

00:34:29,820 --> 00:34:33,210
that we can add to our
lives' interpretations

803
00:34:33,210 --> 00:34:37,740
and understandings by engaging
in interdisciplinarity.

804
00:34:37,740 --> 00:34:40,410
That said, there's something
that's unique to physics,

805
00:34:40,410 --> 00:34:42,660
and I think that to be a physicist,

806
00:34:42,660 --> 00:34:45,990
one really needs to focus
very hard on the physics.

807
00:34:45,990 --> 00:34:48,180
But something like steampunk

808
00:34:48,180 --> 00:34:51,330
can provide extra energy and inspiration.

809
00:34:51,330 --> 00:34:53,850
- Growing up, were you reading
science fiction novels,

810
00:34:53,850 --> 00:34:56,460
or were you studying thermodynamics?

811
00:34:56,460 --> 00:34:59,610
How did sort of your
formative years lead you

812
00:34:59,610 --> 00:35:00,633
in this direction?

813

00:35:01,500 --> 00:35:04,230
- I grew up reading just
about everything just

814
00:35:04,230 --> 00:35:05,085
about all the time.

815
00:35:05,085 --> 00:35:06,450
(Colin laughs)

816
00:35:06,450 --> 00:35:08,910
I read while waiting to get picked up

817
00:35:08,910 --> 00:35:10,590
from school in the afternoon.

818
00:35:10,590 --> 00:35:15,420
I read while waiting for food
to arrive at restaurants.

819
00:35:15,420 --> 00:35:18,990
I read on weekends. I read after school.

820
00:35:18,990 --> 00:35:23,130
This reading taught me to
build worlds in my head.

821
00:35:23,130 --> 00:35:27,480
I always had characters and
plots and settings in my head.

822
00:35:27,480 --> 00:35:31,260
I think of my job now
as building universes

823
00:35:31,260 --> 00:35:33,030
in my head for a living.

824
00:35:33,030 --> 00:35:37,500

- So we've already asked you
about how you got interested

825
00:35:37,500 --> 00:35:39,870
in the specific field of
quantum thermodynamics,

826
00:35:39,870 --> 00:35:42,300
but I'm wondering if you
can also share with us

827
00:35:42,300 --> 00:35:45,720
how you came to find
yourself as a physicist.

828
00:35:45,720 --> 00:35:48,330
- I did want to study everything,

829
00:35:48,330 --> 00:35:51,764
so I resisted choosing a
major as long as possible.

830
00:35:51,764 --> 00:35:53,153
- That was at Dartmouth?

831
00:35:53,153 --> 00:35:55,980
- Yes, at Dartmouth
College in New Hampshire.

832
00:35:55,980 --> 00:35:58,800
I had always had
philosophical inclinations.

833
00:35:58,800 --> 00:36:03,800
I always enjoyed engaging
with abstract ideas.

834
00:36:04,620 --> 00:36:07,110
I had a philosophy teacher in high school

835
00:36:07,110 --> 00:36:10,380
who was fascinated by the paradoxes

836
00:36:10,380 --> 00:36:12,870
in quantum theory and relativity.

837
00:36:12,870 --> 00:36:16,530
He didn't have any background in physics,

838
00:36:16,530 --> 00:36:18,150
he would be the first to admit,

839
00:36:18,150 --> 00:36:21,780
but he passed on to me a
curiosity about these fields.

840
00:36:21,780 --> 00:36:25,200
Meanwhile, I was absolutely
adoring my calculus class

841
00:36:25,200 --> 00:36:27,240
and my physics class and so on.

842
00:36:27,240 --> 00:36:29,700
I absolutely wanted to
keep studying those.

843
00:36:29,700 --> 00:36:32,730
I found in the physics department a number

844
00:36:32,730 --> 00:36:37,730
of faculty members who were
extremely good physicists.

845
00:36:38,100 --> 00:36:40,980
I've come to appreciate that more and more

846
00:36:40,980 --> 00:36:42,690

as I've become a colleague

847
00:36:42,690 --> 00:36:46,530
and been able to look at
their works as a colleague.

848
00:36:46,530 --> 00:36:49,680
They also had philosophical inclinations.

849
00:36:49,680 --> 00:36:52,620
They also appreciated history.

850
00:36:52,620 --> 00:36:54,213
They helped me construct a major

851
00:36:54,213 --> 00:36:56,430
that was partway between the physics major

852
00:36:56,430 --> 00:36:58,590
and the create your own major.

853
00:36:58,590 --> 00:37:00,630
I took a bunch of physics courses,

854
00:37:00,630 --> 00:37:02,280
and I took math, philosophy,

855
00:37:02,280 --> 00:37:04,650
and history courses related to physics.

856
00:37:04,650 --> 00:37:06,390
I got to call this major.

857
00:37:06,390 --> 00:37:08,730
My spirit was very much in the
physics department, though.

858
00:37:08,730 --> 00:37:12,420

And by the end of my undergrad experience,

859
00:37:12,420 --> 00:37:14,040
I determined that it was physics

860
00:37:14,040 --> 00:37:16,680
that I wanted to burrow into very deeply.

861
00:37:16,680 --> 00:37:20,520
So after that, I tried out
research as a research assistant

862
00:37:20,520 --> 00:37:24,480
in Lancaster University
in the United Kingdom.

863
00:37:24,480 --> 00:37:27,510
Then I came to the Perimeter Institute.

864
00:37:27,510 --> 00:37:29,640
And here, I had my first opportunity

865
00:37:29,640 --> 00:37:31,800
to do research on the intersection

866
00:37:31,800 --> 00:37:34,380
of quantum information
theory and thermodynamics,

867
00:37:34,380 --> 00:37:36,930
and I absolutely adored it.

868
00:37:36,930 --> 00:37:39,210
- What did you adore about it so much?

869
00:37:39,210 --> 00:37:41,310
- I love the foundational perspective.

870

00:37:41,310 --> 00:37:43,740
I love the abstract ideas.

871
00:37:43,740 --> 00:37:47,195
Entropy is a strange idea

872
00:37:47,195 --> 00:37:49,550
and entropy-
- Thank you. I thought so.

873
00:37:49,550 --> 00:37:51,810
- And entropy is a function.

874
00:37:51,810 --> 00:37:53,970
You can write down the mathematical form

875
00:37:53,970 --> 00:37:55,800
of a typical entropy.

876
00:37:55,800 --> 00:37:57,720
And it looks funny.

877
00:37:57,720 --> 00:38:01,290
It has multiple pieces
that are kind of odd.

878
00:38:01,290 --> 00:38:02,460
It has a negative sign.

879
00:38:02,460 --> 00:38:06,810
It has two copies of a
probability. It has a logarithm.

880
00:38:06,810 --> 00:38:08,580
There are good reasons

881
00:38:08,580 --> 00:38:11,640
why this entropy has
this mathematical form,

882
00:38:11,640 --> 00:38:14,130
and I go through such an argument

883
00:38:14,130 --> 00:38:16,830
in my book for why it makes sense,

884
00:38:16,830 --> 00:38:19,890
but if you just look at it,
it looks like an odd duck.

885
00:38:19,890 --> 00:38:21,420
But on the other hand,

886
00:38:21,420 --> 00:38:24,150
entropy lies behind the
second law of thermodynamics,

887
00:38:24,150 --> 00:38:27,060
which helps us understand why time flows.

888
00:38:27,060 --> 00:38:29,430
That is so very fundamental.

889
00:38:29,430 --> 00:38:34,110
This tension between that
funny-looking function

890
00:38:34,110 --> 00:38:38,370
and the very fundamental idea
had drawn me for a long time.

891
00:38:38,370 --> 00:38:39,390
Also, as I mentioned,

892
00:38:39,390 --> 00:38:42,300
I've always had
philosophical inclinations.

893
00:38:42,300 --> 00:38:46,020
I appreciated the fundamental nature

894
00:38:46,020 --> 00:38:48,120
of the laws of thermodynamics

895
00:38:48,120 --> 00:38:51,960
and the axioms of quantum theory.

896
00:38:51,960 --> 00:38:55,650
I appreciated how quantum
information theory sits

897
00:38:55,650 --> 00:38:58,920
at the balance between
the very fundamental,

898
00:38:58,920 --> 00:39:01,740
we get to think of some of
the most entrancing paradoxes

899
00:39:01,740 --> 00:39:05,400
of our universe, and applications.

900
00:39:05,400 --> 00:39:07,050
People are building quantum computers

901
00:39:07,050 --> 00:39:09,390
and quantum sensing that can be useful.

902
00:39:09,390 --> 00:39:11,373
I appreciated that balance.

903
00:39:12,330 --> 00:39:14,250
- So, Nicole, we've been
talking to you a lot

904
00:39:14,250 --> 00:39:16,950

about your book, but I
wanna make sure we also talk

905
00:39:16,950 --> 00:39:19,470
about your research contributions.

906
00:39:19,470 --> 00:39:21,600
And so I attended your colloquium here

907
00:39:21,600 --> 00:39:22,830
at Perimeter yesterday,

908
00:39:22,830 --> 00:39:24,870
and at one point, you had a slide

909
00:39:24,870 --> 00:39:28,920
and it was called Many-Body
Localization Auto Cycles.

910
00:39:28,920 --> 00:39:30,420
And I'm not gonna ask you about that,

911
00:39:30,420 --> 00:39:32,730
but at the bottom of the slide,

912
00:39:32,730 --> 00:39:35,107
you had some small text that said,

913
00:39:35,107 --> 00:39:38,520
"Ask me about my favorite symmetries."

914
00:39:38,520 --> 00:39:40,950
So since you said, I have to ask:

915
00:39:40,950 --> 00:39:44,193
Can you tell us about those
favorite symmetries of yours?

916

00:39:45,210 --> 00:39:47,190
- One growing subfield

917
00:39:47,190 --> 00:39:49,560
that I've been dedicating a lot of time to

918
00:39:49,560 --> 00:39:52,320
is a quantum generalization

919
00:39:52,320 --> 00:39:55,140
of a very, very simple problem

920
00:39:55,140 --> 00:39:58,170
from undergraduate statistical physics

921
00:39:58,170 --> 00:40:00,000
or thermodynamics class.

922
00:40:00,000 --> 00:40:04,980
Very often we think about a
small system exchanging stuff

923
00:40:04,980 --> 00:40:06,420
with a big environment.

924
00:40:06,420 --> 00:40:09,660
One of the favorite
examples in thermodynamics

925
00:40:09,660 --> 00:40:11,760
is a cup of coffee.

926
00:40:11,760 --> 00:40:13,110
A cup of coffee cools,

927
00:40:13,110 --> 00:40:17,400
it exchanges heats and particles
with the air around it.

928
00:40:17,400 --> 00:40:19,170
We often think about this small system

929
00:40:19,170 --> 00:40:21,630
as exchanging energy or particles

930
00:40:21,630 --> 00:40:24,540
or maybe electric charge
with the environment.

931
00:40:24,540 --> 00:40:28,920
These are properties that are measurable.

932
00:40:28,920 --> 00:40:33,630
Quantum systems have
properties that are measurable,

933
00:40:33,630 --> 00:40:37,530
but that you might not be able
to measure simultaneously.

934
00:40:37,530 --> 00:40:41,430
They participate in
uncertainty relations together.

935
00:40:41,430 --> 00:40:44,490
What's really interesting
about quantum theory

936
00:40:44,490 --> 00:40:48,480
is what happens when you
have these properties

937
00:40:48,480 --> 00:40:50,460
that can't be measured simultaneously,

938
00:40:50,460 --> 00:40:53,373
that participate in an
uncertainty relation.

939
00:40:54,240 --> 00:40:57,900
Very oddly, across the decades

940
00:40:57,900 --> 00:41:02,550
from the origins of this
problem until a few years ago,

941
00:41:02,550 --> 00:41:06,120
people basically didn't
think of the question,

942
00:41:06,120 --> 00:41:08,520
what happens to this simple setup

943
00:41:08,520 --> 00:41:12,960
that I've described that is
in many an undergrad textbook

944
00:41:12,960 --> 00:41:16,860
if the properties that
the small system exchanges

945
00:41:16,860 --> 00:41:21,860
with the big environment are
these incompatible properties

946
00:41:21,870 --> 00:41:23,640
that we can't measure simultaneously

947
00:41:23,640 --> 00:41:26,310
and that participate in
an uncertainty relation?

948
00:41:26,310 --> 00:41:28,170
It's a really, really basic question

949
00:41:28,170 --> 00:41:31,350
because it takes a textbook problem

950
00:41:31,350 --> 00:41:33,810
and adds one quantum twist.

951
00:41:33,810 --> 00:41:36,570
But some very common arguments

952
00:41:36,570 --> 00:41:40,650
in thermodynamics rely on
the assumption implicitly

953
00:41:40,650 --> 00:41:43,200
that we didn't realize
until a few years ago

954
00:41:43,200 --> 00:41:47,360
that these properties are
simultaneously measurable.

955
00:41:47,360 --> 00:41:50,730
So my group, as well as some
other groups around the world,

956
00:41:50,730 --> 00:41:55,290
are exploring the rather
quantum thermodynamic question

957
00:41:55,290 --> 00:41:58,380
of what happens if we
take this simple setup

958
00:41:58,380 --> 00:42:02,100
and enable the properties
to be incompatible?

959
00:42:02,100 --> 00:42:03,990
It turns out it's not clear

960
00:42:03,990 --> 00:42:06,980

whether the small system
can even thermalize.

961
00:42:06,980 --> 00:42:09,420
so come to be at the same temperature

962
00:42:09,420 --> 00:42:12,270
and so on as its environment.

963
00:42:12,270 --> 00:42:14,610
- A lot of the research
that you're describing here

964
00:42:14,610 --> 00:42:16,800
and in the book seems very cutting edge

965
00:42:16,800 --> 00:42:18,960
and theoretical sort of blackboard work,

966
00:42:18,960 --> 00:42:19,950
but it's not entirely.

967
00:42:19,950 --> 00:42:23,580
There are connections to
experiment and to application.

968
00:42:23,580 --> 00:42:25,980
Can you tell us where
we are in that process

969
00:42:25,980 --> 00:42:27,540
between theory and experiment

970
00:42:27,540 --> 00:42:31,530
and application in
quantum steampunk terms?

971
00:42:31,530 --> 00:42:32,363
- Yes.

972
00:42:32,363 --> 00:42:35,880
Quantum thermodynamics
has its roots in theory

973
00:42:35,880 --> 00:42:40,470
for quantum thermodynamics
developed first during the 1930s.

974
00:42:40,470 --> 00:42:44,340
There was some work during
the ensuing decades.

975
00:42:44,340 --> 00:42:48,960
There has really been a
huge burst of activity

976
00:42:48,960 --> 00:42:50,850
over the past decade or so.

977
00:42:50,850 --> 00:42:55,080
The earlier quantum thermodynamic
works were theoretical

978
00:42:55,080 --> 00:42:58,980
and even, to some extent,
philosophically minded.

979
00:42:58,980 --> 00:43:00,810
That drew me into the field

980
00:43:00,810 --> 00:43:03,780
and drew me in part to Perimeter.

981
00:43:03,780 --> 00:43:04,950
Then I went to Caltech,

982
00:43:04,950 --> 00:43:08,190
which has a lot of experimental activity.

983
00:43:08,190 --> 00:43:10,080
So I was increasingly exposed

984
00:43:10,080 --> 00:43:13,140
to experiment during the course of my PhD,

985
00:43:13,140 --> 00:43:16,680
increasingly came to interact
with experimentalists.

986
00:43:16,680 --> 00:43:19,260
And as a postdoc, I ended up starting

987
00:43:19,260 --> 00:43:20,460
to collaborate a whole lot

988
00:43:20,460 --> 00:43:22,770
with lots of different
experimental groups.

989
00:43:22,770 --> 00:43:24,600
That's also kind of the story

990
00:43:24,600 --> 00:43:27,420
of how quantum
thermodynamics has progressed

991
00:43:27,420 --> 00:43:29,523
from theory to experiment.

992
00:43:30,390 --> 00:43:33,660
The past decade has seen the ability

993
00:43:33,660 --> 00:43:37,680
to perform quantum
experiments that the founders

994

00:43:37,680 --> 00:43:40,680
of quantum theory thought
would be impossible.

995
00:43:40,680 --> 00:43:43,140
Experimentalists have amazing control

996
00:43:43,140 --> 00:43:47,190
over atoms, ions, photons,

997
00:43:47,190 --> 00:43:49,440
artificial atoms, and more.

998
00:43:49,440 --> 00:43:51,510
Quantum thermodynamicists
have increasingly

999
00:43:51,510 --> 00:43:53,940
been taking advantage of

1000
00:43:53,940 --> 00:43:56,850
that wonderful control achieved in labs.

1001
00:43:56,850 --> 00:44:00,030
Labs have been realizing quantum engines

1002
00:44:00,030 --> 00:44:03,750
that have been proposed
since the late 1950s.

1003
00:44:03,750 --> 00:44:06,780
They've been realizing refrigerators

1004
00:44:06,780 --> 00:44:09,300
and quantum batteries and so on.

1005
00:44:09,300 --> 00:44:12,030
- And some of your own
research is currently being put

1006
00:44:12,030 --> 00:44:13,170
to the experimental test.

1007
00:44:13,170 --> 00:44:14,160
Is that right?

1008
00:44:14,160 --> 00:44:17,940
- Yes, I am currently
working with four labs.

1009
00:44:17,940 --> 00:44:20,850
One uses photons, one uses ions,

1010
00:44:20,850 --> 00:44:23,040
and two use artificial atoms.

1011
00:44:23,040 --> 00:44:25,260
- And what is the the
goal of that research

1012
00:44:25,260 --> 00:44:27,510
or the focus of it?

1013
00:44:27,510 --> 00:44:30,240
- Different projects
have different focuses.

1014
00:44:30,240 --> 00:44:34,680
For instance, an experiment
that was recently completed was

1015
00:44:34,680 --> 00:44:37,050
in this subfield of quantum thermodynamics

1016
00:44:37,050 --> 00:44:39,450
that I just discussed,

1017

00:44:39,450 --> 00:44:44,450
that involves the exchange
of thermodynamic properties

1018
00:44:44,580 --> 00:44:47,520
that can be quantum incompatible.

1019
00:44:47,520 --> 00:44:49,620
It was not clear for a while

1020
00:44:49,620 --> 00:44:52,440
that this little system analogous

1021
00:44:52,440 --> 00:44:55,230
to the coffee cup could thermalize,

1022
00:44:55,230 --> 00:44:57,330
come to a quiet state,

1023
00:44:57,330 --> 00:45:00,000
in which there's no net flow of anything,

1024
00:45:00,000 --> 00:45:02,700
such as energy or particles in and out,

1025
00:45:02,700 --> 00:45:04,320
and it has the same temperature

1026
00:45:04,320 --> 00:45:07,740
and some other properties
as its environment.

1027
00:45:07,740 --> 00:45:12,000
We've increasingly gained
evidence that this small system,

1028
00:45:12,000 --> 00:45:14,700
even in this particularly quantum setup,

1029
00:45:14,700 --> 00:45:17,910
at least approaches thermalization,

1030
00:45:17,910 --> 00:45:21,360
although we don't know exactly
to what extent it does.

1031
00:45:21,360 --> 00:45:23,850
Together, with some theorist colleagues,

1032
00:45:23,850 --> 00:45:27,420
proposed an experiment for
observing whatever degree

1033
00:45:27,420 --> 00:45:29,220
of thermalization we could.

1034
00:45:29,220 --> 00:45:30,720
Christian Roos' group

1035
00:45:30,720 --> 00:45:35,720
in Innsbruck, Austria
used a set of trapped ions

1036
00:45:36,330 --> 00:45:38,400
as their whole system,

1037
00:45:38,400 --> 00:45:40,830
the small system and the environment.

1038
00:45:40,830 --> 00:45:43,620
A couple of the ions formed
the little system analogous

1039
00:45:43,620 --> 00:45:44,520
to the cup of coffee,

1040
00:45:44,520 --> 00:45:46,650

and the rest of the ions

1041
00:45:46,650 --> 00:45:51,000
in a chain of ions formed
the environment analogous

1042
00:45:51,000 --> 00:45:55,500
to the air with which the
coffee cup exchanges heats

1043
00:45:55,500 --> 00:45:56,540
and particles.

1044
00:45:56,540 --> 00:46:00,090
So they set up these
ions in a certain way.

1045
00:46:00,090 --> 00:46:03,060
They let the ions evolve

1046
00:46:03,060 --> 00:46:05,790
and exchange different properties.

1047
00:46:05,790 --> 00:46:07,680
Then they measured the two ions

1048
00:46:07,680 --> 00:46:10,080
and found that they did

1049
00:46:10,080 --> 00:46:13,380
at least approach thermal equilibrium.

1050
00:46:13,380 --> 00:46:15,810
- You mentioned quantum refrigerator.

1051
00:46:15,810 --> 00:46:16,980
Can you explain what that is?

1052

00:46:16,980 --> 00:46:18,990
Again, it's not a very small refrigerator.

1053
00:46:18,990 --> 00:46:21,150
It's something else entirely,

1054
00:46:21,150 --> 00:46:22,410
but we have this picture in our heads

1055
00:46:22,410 --> 00:46:24,600
of what a refrigerator
is and what it's for.

1056
00:46:24,600 --> 00:46:26,040
Is that picture at all related

1057
00:46:26,040 --> 00:46:29,520
to the quantum analogous refrigerator?

1058
00:46:29,520 --> 00:46:32,460
- I think of a refrigerator as anything

1059
00:46:32,460 --> 00:46:36,720
that uses a resource
to cool down a system.

1060
00:46:36,720 --> 00:46:40,020
I'm working with Simone Gasparinetti's lab

1061
00:46:40,020 --> 00:46:42,810
in Sweden at Chalmers University

1062
00:46:42,810 --> 00:46:45,540
on building a quantum refrigerator.

1063
00:46:45,540 --> 00:46:48,840
It consists of superconducting qubits.

1064

00:46:48,840 --> 00:46:52,080
Superconductors are quantum systems.

1065
00:46:52,080 --> 00:46:55,800
They're little circuits
in which current can flow

1066
00:46:55,800 --> 00:46:58,470
for all time without ever dissipating.

1067
00:46:58,470 --> 00:47:01,290
Superconducting qubits are being used

1068
00:47:01,290 --> 00:47:03,090
as the physical systems

1069
00:47:03,090 --> 00:47:07,110
that encode basic units
of quantum information

1070
00:47:07,110 --> 00:47:08,640
in many quantum computers.

1071
00:47:08,640 --> 00:47:12,030
Chalmers University is
building a quantum computer.

1072
00:47:12,030 --> 00:47:14,190
A superconducting qubit
quantum computer needs

1073
00:47:14,190 --> 00:47:16,020
to be at low temperatures.

1074
00:47:16,020 --> 00:47:19,620
If the quantum computer
has just run a calculation,

1075
00:47:19,620 --> 00:47:23,790

then it's effectively
filled up its scrap paper.

1076
00:47:23,790 --> 00:47:26,370
These superconducting
qubits act like scrap paper

1077
00:47:26,370 --> 00:47:27,930
that has been scribbled on.

1078
00:47:27,930 --> 00:47:29,640
They need to be reset.

1079
00:47:29,640 --> 00:47:31,230
They need to be, in a sense,

1080
00:47:31,230 --> 00:47:34,410
erased like scrap paper
for the next calculation.

1081
00:47:34,410 --> 00:47:38,520
They are reset if they
are cooled down even more.

1082
00:47:38,520 --> 00:47:42,780
This quantum refrigerator will be inside

1083
00:47:42,780 --> 00:47:46,050
of the preexisting classical refrigerator

1084
00:47:46,050 --> 00:47:48,750
that keeps all of the
superconducting qubits

1085
00:47:48,750 --> 00:47:50,250
at a low temperature.

1086
00:47:50,250 --> 00:47:52,680
And the quantum refrigerator has the job

1087
00:47:52,680 --> 00:47:57,180
of cooling down these
used qubits even more.

1088
00:47:57,180 --> 00:48:00,840
The experiment is supposed
to be happening right now.

1089
00:48:00,840 --> 00:48:02,850
We have numerical simulations.

1090
00:48:02,850 --> 00:48:06,000
We'll see how well those are born out.

1091
00:48:06,000 --> 00:48:07,590
- I've heard you talk about the fact

1092
00:48:07,590 --> 00:48:11,640
that the initial idea for one
of your research projects,

1093
00:48:11,640 --> 00:48:13,710
which I know has now been published

1094
00:48:13,710 --> 00:48:15,510
with a team of your collaborators,

1095
00:48:15,510 --> 00:48:19,680
first came up over an informal
discussion over coffee.

1096
00:48:19,680 --> 00:48:21,270
And I think this type

1097
00:48:21,270 --> 00:48:23,610
of thing actually happens pretty often,

1098

00:48:23,610 --> 00:48:25,080
maybe more often than we might think.

1099
00:48:25,080 --> 00:48:27,840
It actually happened to
me as well during my PhD

1100
00:48:27,840 --> 00:48:30,750
that a project that I ended
up spending a lot of time

1101
00:48:30,750 --> 00:48:33,360
on came up over a discussion at lunch.

1102
00:48:33,360 --> 00:48:35,340
Although, I wasn't part
of that discussion,

1103
00:48:35,340 --> 00:48:37,980
but I ended up working on the project

1104
00:48:37,980 --> 00:48:40,350
that resulted from that discussion.

1105
00:48:40,350 --> 00:48:43,650
I'm just wondering if you can
talk a little bit about that

1106
00:48:43,650 --> 00:48:45,960
and maybe what you think is so special

1107
00:48:45,960 --> 00:48:48,660
about those spontaneous discussions

1108
00:48:48,660 --> 00:48:50,733
that between researchers.

1109
00:48:51,900 --> 00:48:54,450
- This collaboration began during my PhD

1110
00:48:54,450 --> 00:48:56,040
when I was at Caltech.

1111
00:48:56,040 --> 00:48:58,860
There is a condensed matter theorist,

1112
00:48:58,860 --> 00:49:00,840
Gil Refael, at Caltech.

1113
00:49:00,840 --> 00:49:04,230
He has an office in a
building called Bridge.

1114
00:49:04,230 --> 00:49:07,350
But most often I saw him
at the Red Door cafe.

1115
00:49:07,350 --> 00:49:11,880
After lunch one day, I
was at the Red Door Cafe,

1116
00:49:11,880 --> 00:49:13,927
he was at the Red Door Cafe, and he said,

1117
00:49:13,927 --> 00:49:15,480
"Hey, you're interested

1118
00:49:15,480 --> 00:49:18,390
in breaking the second law
of thermodynamics, right?"

1119
00:49:18,390 --> 00:49:21,270
Personally, I think that the
second law of thermodynamics

1120
00:49:21,270 --> 00:49:23,220
probably cannot be broken,

1121
00:49:23,220 --> 00:49:26,400
but I am extremely enthusiastic

1122
00:49:26,400 --> 00:49:28,290
about the second law of thermodynamics.

1123
00:49:28,290 --> 00:49:31,320
So I asked, "What are you
interested in discussing?"

1124
00:49:31,320 --> 00:49:33,810
And he said, "There's
this phase of matter,

1125
00:49:33,810 --> 00:49:35,550
many-body localization."

1126
00:49:35,550 --> 00:49:38,430
This phase was very, very popular.

1127
00:49:38,430 --> 00:49:42,300
It was undergoing a lot of
study when I was in my PhD.

1128
00:49:42,300 --> 00:49:45,420
Gil contributed a lot to that research.

1129
00:49:45,420 --> 00:49:48,810
He said, "We've been studying
many-body localization

1130
00:49:48,810 --> 00:49:49,860
for a while now.

1131
00:49:49,860 --> 00:49:52,500
And it's interesting from
a physics perspective,

1132

00:49:52,500 --> 00:49:54,990
but what is it good for?"

1133
00:49:54,990 --> 00:49:58,950
So many-body localization
is a phase of matter

1134
00:49:58,950 --> 00:50:02,040
of quantum many-particle systems.

1135
00:50:02,040 --> 00:50:06,000
The behavior of a many-body
localized system contrasts

1136
00:50:06,000 --> 00:50:09,240
with ordinary behavior
that we might expect.

1137
00:50:09,240 --> 00:50:11,460
Let's go back to the example

1138
00:50:11,460 --> 00:50:14,340
of a classical gas in a box.

1139
00:50:14,340 --> 00:50:18,240
Suppose that we have a
classical gas in a box,

1140
00:50:18,240 --> 00:50:20,940
we measure its particles' positions,

1141
00:50:20,940 --> 00:50:23,820
and we find that the particles
are all clumped together

1142
00:50:23,820 --> 00:50:25,980
in one corner of the box.

1143
00:50:25,980 --> 00:50:27,390

Shortly thereafter,

1144
00:50:27,390 --> 00:50:29,760
the particles will
spread all over the box.

1145
00:50:29,760 --> 00:50:33,030
They won't hang around
in the same positions.

1146
00:50:33,030 --> 00:50:36,930
However, if we have a
many-body localized system,

1147
00:50:36,930 --> 00:50:40,740
which could consist of
a bunch of cold atoms,

1148
00:50:40,740 --> 00:50:45,450
and we measure the positions
of these particles,

1149
00:50:45,450 --> 00:50:48,330
then those particles will
approximately hang around

1150
00:50:48,330 --> 00:50:51,090
in the positions for
a long time afterward,

1151
00:50:51,090 --> 00:50:53,943
in contrast with the behavior
that we would expect.

1152
00:50:54,780 --> 00:50:58,080
A many-body localized
system has some resistance

1153
00:50:58,080 --> 00:51:01,770
to the second law of thermodynamics

and the flow of time.

1154
00:51:01,770 --> 00:51:04,140
If we're thinking about
the classical gas in a box,

1155
00:51:04,140 --> 00:51:06,810
we know time is flowing
if we're watching the gas

1156
00:51:06,810 --> 00:51:10,320
because we see the gas
expanding all across the box.

1157
00:51:10,320 --> 00:51:12,510
That's why we think of
many-body localization as,

1158
00:51:12,510 --> 00:51:15,810
in some sense, resisting the
second law of thermodynamics

1159
00:51:15,810 --> 00:51:17,250
a little bit, although, eventually,

1160
00:51:17,250 --> 00:51:19,320
the particles do spread out.

1161
00:51:19,320 --> 00:51:22,170
Many-body localization had been proposed

1162
00:51:22,170 --> 00:51:24,780
as a possible quantum memory

1163
00:51:24,780 --> 00:51:26,970
for storing quantum information

1164
00:51:26,970 --> 00:51:29,940
since things tend to stay put in it.

1165
00:51:29,940 --> 00:51:31,860
But Gil was thinking,

1166
00:51:31,860 --> 00:51:34,680
just as there are
information processing tasks,

1167
00:51:34,680 --> 00:51:36,810
such as storing information,

1168
00:51:36,810 --> 00:51:39,210
there are also thermodynamic tasks.

1169
00:51:39,210 --> 00:51:41,280
So maybe I should ask a
quantum thermodynamicist

1170
00:51:41,280 --> 00:51:43,530
what we can do with this resource.

1171
00:51:43,530 --> 00:51:46,410
We talked for a while,
and we eventually brought

1172
00:51:46,410 --> 00:51:49,320
into the project two more collaborators:

1173
00:51:49,320 --> 00:51:52,950
Christopher White and
Sarang Gopalakrishnan.

1174
00:51:52,950 --> 00:51:57,330
We came up with the
idea of a quantum engine

1175
00:51:57,330 --> 00:52:00,000
that can be changed

1176
00:52:00,000 --> 00:52:02,670
between this many-body localized phase

1177
00:52:02,670 --> 00:52:05,670
and a more thermalizing phase of matter

1178
00:52:05,670 --> 00:52:09,060
in which particles and
information spread out quickly.

1179
00:52:09,060 --> 00:52:11,910
Many-body localization is a long name

1180
00:52:11,910 --> 00:52:15,420
that has very many letters and syllables,

1181
00:52:15,420 --> 00:52:18,300
so it's often called MBL.

1182
00:52:18,300 --> 00:52:20,850
Gil came up with a wonderful
name for the engine,

1183
00:52:20,850 --> 00:52:22,023
the MBL mobile.

1184
00:52:23,310 --> 00:52:25,830
- We've been asking you
a lot about your book

1185
00:52:25,830 --> 00:52:26,850
and now about your research,

1186
00:52:26,850 --> 00:52:28,800
but I also wanna ask you
about something kind of

1187
00:52:28,800 --> 00:52:30,720

at the intersection of those two.

1188
00:52:30,720 --> 00:52:33,360
Can you tell us if writing
the book helped you at all

1189
00:52:33,360 --> 00:52:34,830
with your research?

1190
00:52:34,830 --> 00:52:37,260
- Absolutely. It was extremely helpful.

1191
00:52:37,260 --> 00:52:41,610
On the one hand, I had to
extract the basic physics

1192
00:52:41,610 --> 00:52:46,050
from a lot of different
thermodynamic discoveries.

1193
00:52:46,050 --> 00:52:50,490
When I think of a highly
competent theoretical physicist

1194
00:52:50,490 --> 00:52:52,770
whom I admire, I think of someone

1195
00:52:52,770 --> 00:52:55,290
who can explain a discovery

1196
00:52:55,290 --> 00:52:58,530
in terms of just the basic physical story.

1197
00:52:58,530 --> 00:53:01,650
That person knows what's really essential,

1198
00:53:01,650 --> 00:53:03,330
what's really important,

1199
00:53:03,330 --> 00:53:06,540
so they don't bog down the explanation

1200
00:53:06,540 --> 00:53:09,000
with a lot of unnecessary details.

1201
00:53:09,000 --> 00:53:11,790
I had to extract the basic physics

1202
00:53:11,790 --> 00:53:13,350
from discoveries in this way,

1203
00:53:13,350 --> 00:53:16,830
and that helped me understand
a lot better what was really

1204
00:53:16,830 --> 00:53:21,830
behind these thermodynamic
settings and findings.

1205
00:53:23,490 --> 00:53:25,560
Also, I had to write at the end

1206
00:53:25,560 --> 00:53:28,140
of my book what I thought
was ahead for the field.

1207
00:53:28,140 --> 00:53:30,870
I started thinking from
quantum thermodynamics,

1208
00:53:30,870 --> 00:53:33,570
we've gained wonderful
fundamental insights.

1209
00:53:33,570 --> 00:53:37,140
Can quantum thermodynamics
also be practical?

1210
00:53:37,140 --> 00:53:39,540
What would it take for
quantum thermodynamics

1211
00:53:39,540 --> 00:53:40,950
to be practical?

1212
00:53:40,950 --> 00:53:43,770
The original theory of
thermodynamics went hand in hand

1213
00:53:43,770 --> 00:53:45,510
with the Industrial Revolution,

1214
00:53:45,510 --> 00:53:48,060
which was extremely practical.

1215
00:53:48,060 --> 00:53:49,410
It would be wonderful

1216
00:53:49,410 --> 00:53:52,620
for the quantum thermodynamic engines

1217
00:53:52,620 --> 00:53:53,880
and refrigerators and so on

1218
00:53:53,880 --> 00:53:58,743
that have been proposed
to lead to utility.

1219
00:53:59,580 --> 00:54:01,170
I mentioned that experimentalists

1220
00:54:01,170 --> 00:54:05,430
have realized quantum
thermodynamic engines.

1221
00:54:05,430 --> 00:54:07,830

These experiments are proof of principle.

1222
00:54:07,830 --> 00:54:10,380
They show that if we work really hard,

1223
00:54:10,380 --> 00:54:13,050
we can create and run quantum engines,

1224
00:54:13,050 --> 00:54:16,710
but we tend to have to invest more work

1225
00:54:16,710 --> 00:54:20,670
in cooling the engine down
and in manipulating it

1226
00:54:20,670 --> 00:54:24,060
than we can extract using the engine,

1227
00:54:24,060 --> 00:54:27,240
which is quantum, so it's
just a little bit of energy.

1228
00:54:27,240 --> 00:54:30,900
I thought about what we would really need

1229
00:54:30,900 --> 00:54:33,300
to make quantum thermodynamics practical.

1230
00:54:33,300 --> 00:54:35,580
I started thinking about solar panels

1231
00:54:35,580 --> 00:54:37,230
in Southern California.

1232
00:54:37,230 --> 00:54:39,090
My PhD advisor, John Preskill,

1233
00:54:39,090 --> 00:54:42,600

has solar panels on his
house in Southern California.

1234
00:54:42,600 --> 00:54:45,390
He can use solar panels to great effect

1235
00:54:45,390 --> 00:54:48,360
because he happens to be in an environment

1236
00:54:48,360 --> 00:54:51,930
where they fit in and just do
their own job very usefully.

1237
00:54:51,930 --> 00:54:54,600
If we were in Buffalo instead,

1238
00:54:54,600 --> 00:54:57,270
solar panels would not be so helpful.

1239
00:54:57,270 --> 00:54:59,520
I think of the quantum engines

1240
00:54:59,520 --> 00:55:01,170
that have been realized today

1241
00:55:01,170 --> 00:55:04,680
as kind of similar to
solar panels in Buffalo.

1242
00:55:04,680 --> 00:55:07,260
We have to spend a lot of work on them,

1243
00:55:07,260 --> 00:55:08,580
just as you would have to spend a lot

1244
00:55:08,580 --> 00:55:12,360
of work scooping snow off
your solar panels in Buffalo.

1245
00:55:12,360 --> 00:55:14,550
I started looking around

1246
00:55:14,550 --> 00:55:17,580
for a quantum thermodynamic context

1247
00:55:17,580 --> 00:55:20,400
for quantum thermodynamic technologies

1248
00:55:20,400 --> 00:55:24,150
that is, frankly, like Southern
California for solar panels.

1249
00:55:24,150 --> 00:55:27,450
Shortly after writing
that section of my book,

1250
00:55:27,450 --> 00:55:30,720
I got an email from Simone Gasparinetti,

1251
00:55:30,720 --> 00:55:33,090
the experimentalist that I mentioned

1252
00:55:33,090 --> 00:55:34,710
who I'm working with in Sweden.

1253
00:55:34,710 --> 00:55:37,057
I was not working with him
at the time, but he said,

1254
00:55:37,057 --> 00:55:38,220
"I'm starting up a lab.

1255
00:55:38,220 --> 00:55:39,060
How about we chat

1256
00:55:39,060 --> 00:55:41,070
about what you think

are great opportunities

1257
00:55:41,070 --> 00:55:43,320
for quantum thermodynamic experiments?"

1258
00:55:43,320 --> 00:55:45,750
And I said, "Recently, I've been thinking

1259
00:55:45,750 --> 00:55:49,950
about this need for a
quantum thermodynamic setting

1260
00:55:49,950 --> 00:55:51,870
that's like Southern
California for solar panels.

1261
00:55:51,870 --> 00:55:54,090
I want to make quantum
thermodynamics useful."

1262
00:55:54,090 --> 00:55:55,110
I should also mention I'm not

1263
00:55:55,110 --> 00:55:57,360
the only quantum
thermodynamicist who would like

1264
00:55:57,360 --> 00:55:59,940
to make quantum
thermodynamic devices useful.

1265
00:55:59,940 --> 00:56:01,650
There are other people
around the world thinking

1266
00:56:01,650 --> 00:56:04,290
in this direction, but
I'm just telling the story

1267

00:56:04,290 --> 00:56:06,390
of how I came to this direction

1268
00:56:06,390 --> 00:56:09,480
and this collaboration
and this experiment.

1269
00:56:09,480 --> 00:56:12,690
And Simone said, "Ah,
I have such a setting."

1270
00:56:12,690 --> 00:56:15,510
And so we embarked on this adventure

1271
00:56:15,510 --> 00:56:19,470
of developing a quantum
thermodynamic refrigerator

1272
00:56:19,470 --> 00:56:21,810
that we wouldn't have to spend a lot

1273
00:56:21,810 --> 00:56:24,270
of control on in operating,

1274
00:56:24,270 --> 00:56:26,640
that would just do its own thing

1275
00:56:26,640 --> 00:56:30,720
to reset qubits after
a quantum computation

1276
00:56:30,720 --> 00:56:33,630
in a superconducting qubit
quantum refrigerator.

1277
00:56:33,630 --> 00:56:36,360
So the book has absolutely been useful

1278
00:56:36,360 --> 00:56:38,849

for my physics research.

1279
00:56:38,849 --> 00:56:39,780
- To follow up on that,

1280
00:56:39,780 --> 00:56:42,210
are there any sort of
big-picture breakthroughs

1281
00:56:42,210 --> 00:56:43,650
or advances in your field?

1282
00:56:43,650 --> 00:56:47,280
That, you know, you're still
quite a young researcher

1283
00:56:47,280 --> 00:56:49,350
with a long runway ahead in research.

1284
00:56:49,350 --> 00:56:51,630
Are there breakthroughs
that you hope you'll see

1285
00:56:51,630 --> 00:56:54,240
or even make in your career?

1286
00:56:54,240 --> 00:56:58,530
- I am very fascinated
by this growing subfield

1287
00:56:58,530 --> 00:56:59,700
that I mentioned before

1288
00:56:59,700 --> 00:57:02,880
that involves incompatible properties

1289
00:57:02,880 --> 00:57:05,676
of quantum thermodynamic systems.

1290
00:57:05,676 --> 00:57:08,070
There are a lot of really
fundamental questions

1291
00:57:08,070 --> 00:57:10,860
that haven't been thought about.

1292
00:57:10,860 --> 00:57:12,480
For instance, to what extent does

1293
00:57:12,480 --> 00:57:15,180
the small system reach
thermal equilibrium?

1294
00:57:15,180 --> 00:57:17,850
Also, I think there are
really interesting discoveries

1295
00:57:17,850 --> 00:57:20,130
to be made when we take this idea

1296
00:57:20,130 --> 00:57:22,320
and bring into other fields.

1297
00:57:22,320 --> 00:57:26,220
For instance, the last time
I was in Santa Barbara,

1298
00:57:26,220 --> 00:57:29,640
I went to a many-body physicist.

1299
00:57:29,640 --> 00:57:34,151
There is toolkits in
many-body physics called,

1300
00:57:34,151 --> 00:57:36,780
it also has a horrendously long name,

1301

00:57:36,780 --> 00:57:38,880
the eigenstate thermalization hypothesis.

1302
00:57:38,880 --> 00:57:42,780
It helps us understand why
quantum systems thermalize.

1303
00:57:42,780 --> 00:57:46,080
Why, in some sense, time flows

1304
00:57:46,080 --> 00:57:49,680
for them in some ways similarly
too for classical systems.

1305
00:57:49,680 --> 00:57:53,310
This many-body physicist in Santa Barbara,

1306
00:57:53,310 --> 00:57:56,580
Mark Srednicki, calls
himself the high priest

1307
00:57:56,580 --> 00:57:59,130
of the eigenstate
thermalization hypothesis.

1308
00:57:59,130 --> 00:58:00,660
He was one of the people

1309
00:58:00,660 --> 00:58:03,540
who helped create this toolkit.

1310
00:58:03,540 --> 00:58:05,190
It's very powerful.

1311
00:58:05,190 --> 00:58:08,370
It has been transformative
for quantum many-body physics.

1312
00:58:08,370 --> 00:58:10,680

It's been used an enormous amount

1313
00:58:10,680 --> 00:58:12,057
over the past few decades.

1314
00:58:12,057 --> 00:58:14,370
And I asked, "What if we try to apply it

1315
00:58:14,370 --> 00:58:17,640
to a system that has these
incompatible properties

1316
00:58:17,640 --> 00:58:19,050
that are being exchanged?"

1317
00:58:19,050 --> 00:58:21,417
And he said, "You know, I
hadn't thought about that."

1318
00:58:21,417 --> 00:58:23,940
And it turns out that this
toolkit needs to be changed.

1319
00:58:23,940 --> 00:58:26,340
This toolkit that has been
around for many decades.

1320
00:58:26,340 --> 00:58:30,150
I think that there are other
such realizations waiting

1321
00:58:30,150 --> 00:58:31,893
to be had in this subfield.

1322
00:58:32,790 --> 00:58:34,320
- You've been so generous with your time,

1323
00:58:34,320 --> 00:58:36,370
and you have a conference to get back to.

1324
00:58:37,260 --> 00:58:39,600
Thank you so much for
sitting down to chat with us.

1325
00:58:39,600 --> 00:58:40,560
It's just been a pleasure.
- Thank you again

1326
00:58:40,560 --> 00:58:41,820
for having me on the podcast.

1327
00:58:41,820 --> 00:58:42,674
It's really been a pleasure.

1328
00:58:42,674 --> 00:58:45,930
(upbeat music)

1329
00:58:45,930 --> 00:58:47,850
- Thanks so much for listening.

1330
00:58:47,850 --> 00:58:49,080
Perimeter Institute is

1331
00:58:49,080 --> 00:58:51,510
a not-for-profit charitable organization

1332
00:58:51,510 --> 00:58:54,120
that shares cutting edge
ideas with the world thanks

1333
00:58:54,120 --> 00:58:55,710
to the ongoing support

1334
00:58:55,710 --> 00:58:58,140
of the governments of Ontario and Canada,

1335
00:58:58,140 --> 00:59:00,390

and also thanks to donors like you.

1336
00:59:00,390 --> 00:59:02,455
Thank you for being part of the equation.

1337
00:59:02,455 --> 00:59:05,038
(upbeat music)