We are in the midst of a culinary revolution, as high-end chefs around the world exploit scientific knowledge and technological advances to create spectacular dishes. Ferran Adrià, known for his world-acclaimed restaurant El Bulli in Catalonia, has pioneered the use of hydrocolloids to create yogurt spheres, carrot foam and other novel foods. Other chefs, such as Heston Blumenthal at the Fat Duck in Bray, UK, Grant Achatz at Alinea, Chicago, and Wylie Dufresne at wd~50, New York, are exploring science-based techniques, including the use of liquid nitrogen, enzymes and controlled temperature baths, to create remarkable juxtapositions of new flavours and unexpected textures.

The same trend is happening, in parallel, with cocktails. For years bartenders have relied on trial and error to refine recipes, but now the same techniques that fuelled the culinary revolution are allowing a more systematic approach to developing new drinks. Tools and techniques borrowed from research laboratories in physics and chemistry, such as rotary evaporators, thermocouples and centrifuges, are helping bartenders to put their innovative drinks ideas into practice. Concepts from thermodynamics as well as the physics of colloids, gels and other forms of “soft matter” can help explain the flavour, appearance and “mouthfeel” of these beverages. So get your cocktail shakers and bar spoons ready as we take you through what you need to know to create cocktails that look, taste and feel fantastic.

Naveen N Sinha is a PhD student at the Harvard School of Engineering and Applied Sciences and David A Weitz is the Mallinckrodt Professor of Physics and Applied Physics at Harvard University, e-mail nsinha@seas.harvard.edu

Naveen N Sinha and David A Weitz explain the theory and techniques behind these increasingly exotic mixed drinks.
Feature: Cocktail physics

At a Glance: Cocktail physics

- Having perfected yoghurt spheres, carrot foam and other novel foods using new technological tools, some chefs are now turning their attention to cocktails.
- Cocktails have traditionally been developed by trial and error but can now be understood in terms of thermodynamics and soft-matter physics.
- The physical properties of ethanol, the basis of every spirit, enable the delivery of flavours impossible to achieve using water alone.
- Equipment such as rotary evaporators and whipped-cream dispensers are now used to extract flavours, along with traditional distillation and soaking methods.
- The appearance and texture of drinks can be controlled by clarification, the decision to stir or shake, or the production of foam, for example using egg whites to stabilize air bubbles.

Get mixing!

Here is a cocktail recipe you can try for yourself, from leader in the field Ferran Adrià.

Hot and cold gin fizz

**Ingredients**

<table>
<thead>
<tr>
<th>For the base syrup:</th>
<th>For the frozen lemon mix:</th>
<th>For the hot lemon foam:</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 g sugar</td>
<td>250 g lemon juice</td>
<td>150 g egg whites</td>
<td>0.5 litre iSi Whip</td>
</tr>
<tr>
<td>150 g water</td>
<td>150 g base syrup (see above)</td>
<td>130 g lemon juice</td>
<td>1 cartridge of N₂O</td>
</tr>
<tr>
<td></td>
<td>150 g gin</td>
<td>70 g gin</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>145 g base syrup (see above)</td>
<td></td>
</tr>
</tbody>
</table>

**Method**

- For the base syrup: Mix ingredients and bring to a boil. Remove from heat, cool, then refrigerate.
- For the frozen lemon mix: Mix all ingredients cold, then freeze. Once frozen, blend in a blender until fluid. Keep in the freezer.
- For the hot lemon foam: Break egg whites with a whisk. Add the remaining ingredients. Strain and pour into the iSi Whip using a funnel. Load the iSi Whip and keep in a water bath at 80°C, shaking occasionally.
- To serve, 3/4 fill a cocktail glass with frozen lemon mix. Top up with hot foam.

**Equipment**

- 0.5 litre iSi Whip
- 1 cartridge of N₂O

Another way to intensify flavour spirits is to soak ingredients in high concentrations of ethanol, thereby infusing the aromatics into the alcohol. This process traditionally requires many days for the ethanol to fully penetrate the ingredients and extract the desired compounds. Now, however, flavour infusion can be achieved in just a few minutes, using a technique pioneered by Dave Arnold, author of the blog *Cooking Issues* and director of culinary technology at the French Culinary Institute in the US. Coffee-flavoured vodka, for example, can be made by combining ground coffee beans and vodka in a whipped-cream dispenser – a pressurized device typically used to create foams such as whipped cream at the touch of a button, now well known by the commercial name “iSi Whip”. What happens is that nitrous oxide, which is also in the canister and under high pressure, dissolves in the vodka. The high pressure of the liquid displaces any air bubbles in the coffee grounds. When the pressure is released, the nitrous oxide rapidly bubbles out of the solution, just as when a can of carbonated drink is opened. Releasing these bubbles draws flavour molecules from the coffee grounds into the vodka, flavouring the alcohol and foundation of flavour, and aromas provide the tremendous variety.” Although we can perceive just five basic tastes on the tongue (sweet, sour, salty, bitter and savoury), there are thousands of aromas that we can sense through olfactory receptors in the nose – be they the caramel notes of rum or the oaky smell of bourbon.

Alcohol is far more effective than water at delivering these aromatic components, since typically they are not especially water-soluble. Water molecules are polar and so prefer to be near other polar molecules to minimize their interaction energy. This encourages non-polar molecules, such as the aromatics, to leave the liquid phase and vaporize into the surrounding air, where they contribute to the aroma of the drink. The presence of ethanol mediates this polar/non-polar interaction and allows high concentrations of aromatics to remain in an aqueous solution. For this reason, ethanol is used to extract and deliver flavours from a range of sources, including flowers, spices, nuts, fruits and herbs.

Distilled alcoholic liquids, called spirits, are the essential component of any cocktail. Naturally fer-
turning it brown. This versatile technique works for a range of porous substances, such as cocoa nibs and a variety of herbs.

By combining spirits with other ingredients, a full spectrum of flavours can be achieved. Tastes can be added through the sweetness of syrups, the sourness of citrus juice, the salt around the rim of a glass or numerous other methods. Aromas can be enhanced with a variety of highly concentrated alcohol-based solutions called tinctures and bitters. Compared with mixed drinks, there is less flexibility in what can be produced with beer or wine because their flavours can only be manipulated through the fermentation and ageing process.

Hot or cold
Whether by dare or by choice, many of you will have experienced the hot, burning sensation you get in your throat and chest if you drink neat vodka or tequila. In fact, too much spirits in a cocktail can overwhelm the desired mix of flavours. The alcohol burn can, however, be reduced by lowering the temperature of the beverage, which is why aquavit, vodka and other straight spirits are often served cold, at temperatures of around –18 °C. Unfortunately, such low temperatures can also diminish the perception of the other tastes and aromas in the drink, so most mixed drinks are served at somewhat warmer temperatures.

The precision of the drink also strongly affects the complex balance between these flavours. A chilled martini, for example – consisting of gin and vermouth – is crisp and balanced, whereas the gin can overwhelm the flavour near room temperature. As McGee explains, “the bartender’s challenge is to make drinks that have a balanced taste foundation and aromas that suit that foundation, and retain that overall structure reasonably well over the drink’s lifetime, as it becomes diluted or warms up”.

Appearance is everything
The flavour of a cocktail is of course important but its appearance and texture also contribute to the overall experience of the drink – be it the layers of the graphically named squashed frog, the creaminess of an eggnog or the showiness of a blue blazer, which is poured between two cups after being set on fire. Flames and decorations aside, a cocktail’s appearance results from a combination of its colour and opacity, both of which can be controlled by the bartender. For a coloured drink, the mixologist selects ingredients that absorb specific wavelengths of light. For example, a rich brown can be obtained using a spirit that has been aged in oak barrels, as this imparts pigment molecules that produce this colour. If you want the finished drink to be clear, all the pigments and particulates must be removed, to prevent light absorption or scattering.

But even with clarified components, the mixing technique can have a dramatic impact on the light-scattering properties of the finished drink. For example, a manhattan, which contains whisky, vermouth and bitters, can become cloudy when shaken. This results from small air bubbles introduced into the beverage while shaking, which are then stabilized by the bitters. A stirred manhattan, in contrast, is clear (figure 2), which is why it is typically served stirred, not shaken, unlike James Bond’s martinis.
As for drinks that are cloudy, their appearance is often caused by the presence of small particulates, although these can be removed by a variety of clarification techniques. Surprisingly, the most common method of clarification – filtration – is rarely used. Instead, some technology-minded bartenders are using other techniques such as centrifugation, which rapidly produces a clear liquid by accelerating the settling of particulates. Indeed, this technique is a particularly good way of clarifying lime juice, which can then be used for transparent gin and tonics or clear, stirred margaritas. Another technique, also developed by Arnold, uses gels made from agar – a naturally occurring polysaccharide – to trap particulates from citrus juices and other non-transparent liquids. Water is boiled with agar to hydrate it, the juice is then added and the solution is allowed to cool to form a gel. The longer pectin fibres and other plant materials become trapped in the agar gel, and a clear liquid weeps out, which contains the much smaller flavour molecules.

There is also plenty of interesting physics going on in cocktails that include anise-flavoured spirits such as pastis, ouzo and absinthe, which contain water-insoluble anethole compounds. Although the anethole dissolves in ethanol because of the alcohol’s unique structure, when these compounds are diluted with water they are no longer soluble, so they form spontaneous emulsions. What happens here is that a highly concentrated suspension of microscopic droplets has been created in the drink that strongly scatters light. Because the droplets are small, these emulsions are stable for months without having to add any stabilizing “surfactant” molecules. This effect is exemplified in a drink called half sinner, half saint, in which a layer of “surfactant” molecules. This effect is exemplified in a drink called half sinner, half saint, in which a layer of

As for drinks that are cloudy, their appearance is often caused by the presence of small particulates, although these can be removed by a variety of clarification techniques. Surprisingly, the most common method of clarification – filtration – is rarely used. Instead, some technology-minded bartenders are using other techniques such as centrifugation, which rapidly produces a clear liquid by accelerating the settling of particulates. Indeed, this technique is a particularly good way of clarifying lime juice, which can then be used for transparent gin and tonics or clear, stirred margaritas. Another technique, also developed by Arnold, uses gels made from agar – a naturally occurring polysaccharide – to trap particulates from citrus juices and other non-transparent liquids. Water is boiled with agar to hydrate it, the juice is then added and the solution is allowed to cool to form a gel. The longer pectin fibres and other plant materials become trapped in the agar gel, and a clear liquid weeps out, which contains the much smaller flavour molecules.

There is also plenty of interesting physics going on in cocktails that include anise-flavoured spirits such as pastis, ouzo and absinthe, which contain water-insoluble anethole compounds. Although the anethole dissolves in ethanol because of the alcohol’s unique structure, when these compounds are diluted with water they are no longer soluble, so they form spontaneous emulsions. What happens here is that a highly concentrated suspension of microscopic droplets has been created in the drink that strongly scatters light. Because the droplets are small, these emulsions are stable for months without having to add any stabilizing “surfactant” molecules. This effect is exemplified in a drink called half sinner, half saint, in which a layer of absinthe is floated on top of a mixture of sweet and dry vermouth. The absinthe spreads downwards, leading to a white layer, caused by the droplets of anethole that travel from the top to the bottom of the glass over the course of several minutes (figure 3).

**Tactile textures**

In addition to flavour and appearance, the “mouthfeel” of a drink is another parameter manipulated by bartenders. Incorporating air via shaking results in a more viscous texture. Egg whites are used in fizzes and sours to stabilize these air bubbles. An extreme example is a Ramos gin fizz, which calls for an exhausting 12 minutes of shaking in the original recipe. The effort is worth it, however, as it results in an extremely creamy, frothy texture. A layer of foam protrudes several centimetres above the rim of the glass and is stiff enough to hold a metal straw vertically at its centre. The long mixing time is needed to divide the air into progressively smaller bubbles, resulting in a stiffer foam. Another class of drinks, called flips, uses whole egg to form an emulsion, leading to a more creamy texture.

Several of the chefs leading the innovations in haute cuisine are also pushing the frontiers of texture in cocktails. Adria serves several novel types of cocktail in his establishments, including a hot and cold gin fizz (see box on p26). Instead of the lengthy shaking of the Ramos gin fizz, an iSi Whip introduces nitrous-oxide bubbles into the top foam layer, which sits on top of a frozen juice layer. At Grant Achatz’ bar, Aviary, Chicago, the cocktail chefs use techniques developed in the Alinea kitchen to create novel forms for the drinks. For instance, they use a modified stalk called tapioca maltodextrin to produce a powdered gin and tonic and ultralow temperatures to make a chewy Pisco sour. Other mixologists, such as Eben Freeman of the Altamarea group, use similar techniques to create a variety of solid cocktails.

These elements of flavour, appearance and texture all contribute to the final perception of the drink. Classic cocktail recipes have survived and evolved as we have learned to improve the balance of these components. But today’s bartenders are seeking inspiration from science to improve these recipes and to invent new concoctions. So let’s raise a glass to science!

**More about:** Cocktail physics

D Arnold *Cooking Issues* www.cookingissues.com
T Conigliaro *Drink Factory* http://drinkfactory.blogspot.com
H McGee 2004 *On Food and Cooking* (Scribner, New York)