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Cocktail physics

Many top chefs are well known for taking a more scientific approach to cooking in recent years, and some “mixologists” are now extending the same philosophy to cocktails. **Naveen N Sinha** and **David A Weitz** explain the theory and techniques behind these increasingly exotic mixed drinks

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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.

Full of flavour

Be it in beer, wine or spirits, the physical properties of ethanol, especially its solubility and volatility, help to deliver flavours that are impossible to achieve using water alone. What we think of as “flavour” actually has two main components: taste and aroma. As food-science author Harold McGee puts it, “Tastes provide the

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	Method
For the base syrup: 150 g sugar 150 g water	*For the base syrup*: Mix ingredients and bring to a boil. Remove from heat, cool, then refrigerate.
For the frozen lemon mix: 250 g lemon juice 150 g base syrup (see above) 150 g gin	*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: 150 g egg whites 130 g lemon juice 70 g gin 145 g base syrup (see above)	*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.
Equipment 0.5 litre iSi Whip 1 cartridge of N_2O	To serve, 3/4 fill a cocktail glass with frozen lemon mix. Top up with hot foam.

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 fermented alcoholic beverages, such as beer and wine, rarely exceed about 20% ethanol by volume, since higher levels are toxic to most of the strains of yeast that produce them. Higher concentrations must therefore be reached through distillation, in which the fermented beverage is heated to preferentially extract the ethanol, which has a lower boiling point than water. The plant material used during fermentation, such as molasses for rum or agave for tequila, gives an intense flavour to the final distilled beverage. Additional plant materials supplied during or after distillation, such as the juniper berries used for making gin, also contribute to the flavour. Because of the high concentration of aromatic molecules extracted from the plants during the production process, spirits are some of the most intensely flavoured foods. Indeed, only a few drops of Chartreuse, a French liqueur made using nearly 130 herbal extracts, can entirely change a cocktail’s flavour.

Distillation has been used for thousands of years to create spirits, going as far back as Mesopotamia and ancient China, but continues to be improved through applications of scientific knowledge. For example, some bartenders, such as the award-winning Tony Conigliaro of London bar 69 Colebrooke Row, are experimenting with a device commonly found in the science lab – the rotary evaporator (figure 1). This device extracts aroma molecules that would otherwise be destroyed by the higher temperatures in traditional distillation techniques. The rotary evaporator lowers the pressure inside a rotating container holding the liquid to be distilled, causing the more volatile components to evaporate and leaving behind the undesirable water, sugar, pigments and other large molecules. A condensing coil uses a coolant to turn the vapours back into a liquid – the final intensely flavoured product – which is collected in a separate flask. A habañero liqueur is one illustrative example: the capsaicin that makes the chilli taste so hot is non-volatile, so only the fruity and floral compounds end up in the distillate, yielding a liqueur that retains all the flavour of the chillies but without any nasty burn.

Another way to intensely 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

1 From lab to kitchen

Dave Arnold, *Cooking Issues*

A rotary evaporator, typically found in a science lab, can be used to extract delicate aroma molecules that would be destroyed by the higher temperatures of traditional distillation. The liquid in the rotating chamber (red) is gently heated while under a vacuum, causing it to vaporize at a lower temperature. The condenser coils (blue) liquefy the vapour, which is collected in the flask on the left (green).

2 Shaken or stirred?

Mike Betancourt and Leo Stein

These manhattan cocktails have identical ingredients, but the shaken version (left) has a froth on the surface and a cloudy appearance, caused by vigorous shaking that incorporates air bubbles, while the stirred version (right) is clear.

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 flavour of a drink also depends on how dilute it is, which in practical terms means how much ice has been mixed into it. Vigorously shaking the mixture rapidly cools the drink within seconds, whereas cooling can take upwards of a few minutes if it is only gently stirred. In both cases, the final temperature of the diluted mixture can be several degrees below the initial temperature of the ice, for essentially the same reason that roads are de-iced by spreading salt on them. Because the entropy of the diluted mixture is far larger than the entropy of the crystalline ice, the ice continues to melt and absorb heat from the mixture even as the mixture cools below 0 °C.

The precise temperature 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.

3 Settling out nicely

Mike Betancourt and Leo Stein

This half sinner, half saint cocktail is clear before the absinthe is added (*a*). But after the absinthe is poured in (*b*), the top of the drink becomes cloudy as a spontaneous emulsion of the oils in the absinthe is formed. After several minutes (*c*), the emulsion drops spread halfway down the glass, producing an opaque white layer.

Half sinner, half saint

This is a traditional-style cocktail made by John Gertsen, bar manager at Drink, Boston. To make it yourself you will need 2 oz sweet vermouth, 2 oz dry vermouth and 1/4 oz absinthe. Add crushed ice to a rocks glass, pour in both vermouths and mix. Float the absinthe on top, as shown above.

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. Adrià 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 starch 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 all raise a glass to science! ■

More about: Cocktail physics

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